OCS Study
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# Marine and Coastal Fishes Subject to Impingement by Cooling-Water Intake Systems in the Northern Gulf of Mexico: An Annotated Bibliography

MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Coastal Marine Institute
Louisiana State University

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## ABOUT THE COVER

Cover photo courtesy of Dr. William Lang, Minerals Management Service.

## ACKNOWLEDGMENTS

This synthesis report was prepared with the assistance of several electronic databases subscribed to by Louisiana State University. The databases were searched electronically using the Cambridge Scientific Abstracts Internet Database Service (CSA), the U.S. Government Printing Office Access service (GPO), the Online Computer Library Center (OCLC), the Louisiana Library Network (LOUIS), the Scholarly Journal Archive (JSTOR), the Institute for Scientific Information (ISI), and the Springer Link, Biblio Line and Ovid Technologies database services. The following databases were searched:

Aquatic Science and Fisheries Abstracts (CSA)

Biology Digest (CSA)

Catalog of U.S. Government Publications (GPO)

Conference Papers Index (CSA)

Ecology Abstracts (CSA)

Electronic Collections Online (OCLC)

Expanded Academic ASAP (LOUIS)

JSTOR (Ecology)

Oceanic Abstracts (CSA)

Science Citation Index (ISI)

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Wildlife and Ecology Studies Worldwide (Biblio Line)

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Zoological Record (Ovid Technologies)

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# INTRODUCTION

Since the early 1970's cooling-water intakes have been identified as having a potential adverse impact on aquatic organisms due to impingement/entrapment and entrainment. To measure the magnitude of this impact, hundreds of studies have been undertaken over the last three decades. The Environmental Protection Agency (EPA) is proposing a series of new rules to address the impingement and entrainment of fishes and shellfish by cooling-water intake systems on all surface waters of the United States. As part of the rule making process, EPA requested information about the species of fish in the Gulf of Mexico and for any information about research conducted on the impingement and entrainment of fishes and other organisms in coastal ecosystems. The Minerals Management Service (MMS) offered to assist the EPA with the gathering of information, since much of what is known in the Gulf of Mexico has been funded by MMS or used by MMS for the preparation of impact statements.

To meet the information needs of MMS and EPA, this study provides an initial annotated bibliography on all available research reported in marine and coastal waters concerning the impingement and entrainment of estuarine and marine organisms by cooling-water intake systems**.**

## DEFINITIONS

Below we quote the definitions EPA promulgated in the regulatory language for the final Phase I 316(b) rule (December 18, 2001 found at 40 CFR 125.83). While these are the most recent regulatory definitions, they do not fully reflect all meanings behind the use of the words in the open literature, particularly those from several years ago.

Cooling-water intake structure means the total physical structure and any associated constructed waterways used to withdraw cooling-water from waters of the U.S. The cooling-water intake structure extends from the point at which water is withdrawn from the surface water source up to, and including, the intake pumps.

Entrainment means the incorporation of all life stages of fish and shellfish with intake water flow entering and passing through a cooling-water intake structure and into a cooling-water system.

Impingement means the entrapment of all life stages of fish and shellfish on the outer part of an intake structure or against a screening device during periods of intake water withdrawal.

## METHODOLOGY

The criteria used to determine whether a reference might be useful or not had to be adjusted as the search progressed. No consideration was given for other closely related topics, such as fish impingement or entrainment by hydropower plants, biofouling in cooling-water systems or effects of discharges of cooling waters in receiving aquatic environments. Only references related to fish impingement/entrapment or entrainment by cooling-water intakes located on marine and estuarine environments were fully considered. Nevertheless, some references on freshwater environments, considered of potential interest are listed on Part IV. References on marine or estuarine environments, other than the northern Gulf of Mexico, were considered relevant because fish species reported out of the target area might give clues about the potential effect of these water intakes on species of the same family or genus, inhabiting the northern Gulf of Mexico. Additionally, the warming effect of the Gulf Stream current distributes, at least seasonally, several fish species north along the U.S. Atlantic coast.

Finally, references regarding mathematical models to estimate fish impingement or entrainment in cooling-water intakes and references regarding mitigation measures to reduce fish impingent or entrainment by cooling-water intakes, were both considered valuable regardless of the type of environment.

The search strategy included preparation of an initial keyword and database lists. All data bases available for searching in the library at Louisiana State University and relevant to aquatic biology were queried to search article titles, abstracts and any other available text in the data bases using the initial list of keywords. The initial keyword list was expanded during the course of the search to add more keywords, phrases or variants or to modify them in order to refine the search for expected results. The final version of the key word list is presented in Table 1.

Nine key words or phrases, their root forms, logical operators (e.g., AND & OR) and wild cards (*) were used to develop the bibliography. Additionally, the *Science Citation Index* database was also used to search forward in time from early references to obtain a list of subsequent publications that cited important early literature.

A laboratory notebook was used to keep track of all database searches, including date, number of results obtained with each query and the identification number of file where each database output with relevant references was stored. A table containing all key words searched in every database and the information mentioned above was prepared (Table 2). Minor changes in the keyword list were made in each database, depending on the particular search characteristics of the database.

A total of 31,610 documents were obtained through 432 individual searches and each database output was reviewed on-line to determine if it contained relevant references. A new file was created and given an identification number each time an output had at least one potential result. However, since several databases are not specific to aquatic biology and some key words are also relevant in other fields (e.g., medicine, physics, etc.), some files contain irrelevant citations. Database outputs containing more than 200 records were not saved and the search query was refined to obtain more specific results.

Almost 200 files containing references with or without abstracts were then scrutinized and an alphabetical list of all potentially useful references was prepared. After the bibliography was completed, references were reviewed again, edited for uniformity, and sorted into four major categories as follows:

Part I: Studies of fish impingement/entrainment by cooling-water intakes in marine and estuarine environments,

Part II: Studies related to assessment of fish impingement/entrainment by cooling-water intakes,

Part III: Studies related to mitigation measures of fish impingement/entrainment by cooling-water intakes, and

Part IV: Other relevant studies related to fish impingement/entrainment by cooling-water intakes.

Finally, a list of all fish species subject to impingement or entrainment, mentioned in the abstracts included here, was prepared and additional information, such as maximum length attained and ocean of occurrence was obtained from literature.

Table 1.

List of Key Words, Phrases and Variants Used for the Database Searches

| Key words | Variants |
|---|---|
| Cooling water | Cooling-water, cooling-water AND intake* cooling-water AND entrain*, cooling-water AND entrap*, cooling-water AND imping* |
| Entrainment | Entrain*, entrained, entraining |
| Entrapment | Entrap*, entrapped, entrapping |
| Fish | Fish entrainment, fish entrapment, fish impingement, fish mortality AND cooling water, fish mortality AND imping*, fish mortality AND oil platforms, fish mortality AND power plants, fish mortality AND water intake |
| Ichthyoplankton | Ichthyoplankton AND entrain*, ichthyoplankton AND entrap*, ichthyoplankton AND imping*, ichthyoplankton AND mortality |
| Impingement | Imping*, impinged, impinging |
| Oil platform | Oil platform AND entrain*, oil platform AND entrap*, oil platform AND imping*, oil platform AND intake*, oil platform AND impact* |
| Power plant | Power plant* AND entrain*, power plant* AND entrap*, power plant* AND impact*, power plant* AND imping* |
| Water intake(s) | Water-intake*, water-intake* AND impact* |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded)

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| ASFA Marine Biotechnology | Cooling water impact | 10/15/02 | 0 | |
| Abstracts, Including: | Cooling water intake | 10/15/02 | 61 | 52 |
| ASFA 1: Biological Sciences | Cooling-water mortality | 10/15/02 | 2 | 44 |
| and Living Resources. | Cooling-water entrainment | 10/15/02 | 3 | 61 |
| ASFA 2: Ocean Technology, | Cooling-water entrapment | 10/15/02 | 0 | |
| Policy and Non-Living | Cooling-water impingement | 10/15/02 | 2 | 60 |
| Resources. | Entrapping | 10/15/02 | 28 | NR |
| ASFA 3: Aquatic Pollution | Fish entrain* | 10/15/02 | 33 | 39 |
| and Environmental Quality. | Fish entrainment | 10/15/02 | 21 | 51 |
| | Fish entrapment | 10/15/02 | 8 | 57 |
| | Fish entrapping | 10/15/02 | 0 | |
| | Fish entrapped | 10/15/02 | 4 | 62 |
| | Fish impinged | 10/15/02 | 7 | 59 |
| | Fish impingement | 10/15/02 | 25 | 41 |
| | Fish impinging | 10/15/02 | 0 | |
| | Fish imping* | 10/15/02 | 32 | 40 |
| | Fish mortality AND cooling water | 10/15/02 | 6 | 49 |
| | Fish mortality AND imping* | 10/15/02 | 5 | 47 |
| | Fish mortality AND oil platforms | 10/15/02 | 0 | |
| | Fish mortality AND power plants | 10/15/02 | 4 | 48 |
| | Fish mortality AND water intake | 10/15/02 | 2 | 50 |
| | Ichthyoplankton entrain* | 10/15/02 | 17 | 42 |
| | Ichthyoplankton entrainment | 10/15/02 | 16 | 53 |
| | Ichthyoplankton entrap* | 10/15/02 | 0 | |
| | Ichthyoplankton imping* | 10/15/02 | 0 | |
| | Ichthyoplankton mortality | 10/15/02 | 8 | 45 |
| | Imping* mortality | 10/15/02 | 6 | 43 |
| | Oil platform | 10/15/02 | 84 | NR |
| | Oil platform entrainment | 10/15/02 | 0 | |
| | Oil platform impact(s) | 10/15/02 | 0 | |
| | Oil platform impingement | 10/15/02 | 0 | |
| | Oil platform intake(s) | 10/15/02 | 0 | |
| | Power plant entrainment | 10/15/02 | 25 | 54 |
| | Power plant entrapment | 10/15/02 | 0 | |
| | Power plant impact | 10/15/02 | 16 | 63 |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Power plant intake | 10/15/02 | 18 | 46 |
| | Power plant impingement | 10/15/02 | 2 | 58 |
| | Water-intake impact | 10/15/02 | 0 | |
| Biological Sciences, | Cooling water | | | |
| including: | Cooling water impact | 10/15/02 | 0 | |
| Ecology Abstracts | Cooling water intake | 10/15/02 | 11 | 84 |
| | Cooling-water mortality | 10/15/02 | 1 | 78 |
| | Cooling-water entrain* | 10/15/02 | 2 | 77 |
| | Cooling-water entrap* | 10/15/02 | 0 | |
| | Fish entrain* AND cooling water | 10/15/02 | 8 | 73 |
| | Fish entrainment | 10/15/02 | 1 | 82 |
| | Fish entrapment | 10/15/02 | 3 | 81 |
| | Fish imping* AND cooling water | 10/15/02 | 7 | 74 |
| | Fish impinging | 10/15/02 | 4 | 83 |
| | Fish impingement | 10/01/02 | 5 | 65 |
| | Fish mortality AND cooling water | 10/15/02 | 1 | 80 |
| | Fish mortality AND imping* | 10/15/02 | 1 | 79 |
| | Fish mortality AND power plants | 10/15/02 | 0 | |
| | Fish mortality AND water intake | 10/15/02 | 0 | |
| | Ichthyoplankton entrain* | 10/15/02 | 1 | 76 |
| | Ichthyoplankton entrap* | 10/15/02 | 0 | |
| | Ichthyoplankton imping* | 10/15/02 | 0 | |
| | Ichthyoplankton mortality | 10/15/02 | 3 | 75 |
| | Impingement | 10/01/02 | 34 | 64 |
| | Oil platform | 10/15/02 | 13 | 89 |
| | Oil platforms | 10/01/02 | 20 | 71 |
| | Oil platform entrain* | 10/15/02 | 0 | |
| | Oil platform entrap* | 10/15/02 | 0 | |
| | Oil platform impact | 10/15/02 | 0 | |
| | Oil platform imping* | 10/15/02 | 0 | |
| | Power plant entrain* | 10/15/02 | 9 | 88 |
| | Power plant entrap* | 10/15/02 | 0 | |
| | Power plant impact | 10/15/02 | 2 | 87 |
| | Power plant intake | 10/15/02 | 5 | 85 |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Power plant imping* | 10/15/02 | 1 | 86 |
| | Water-intake and imping* | 10/15/02 | 2 | 89 |
| | Water-intake entrap* | 10/15/02 | 0 | |
| | Water-intake impact | 10/15/02 | 0 | |
| Biology Digest | Cooling water | 10/18/02 | 4 | 91 |
| | Cooling water intake | 10/18/02 | 1 | 90 |
| | Cooling-water entrainment | 10/18/02 | 0 | |
| | Cooling-water entrapment | 10/18/02 | 0 | |
| | Cooling-water impingement | 10/18/02 | 0 | |
| | Entrain* | 10/18/02 | 23 | 92 |
| | Entrained | 10/18/02 | 7 | NR |
| | Entraining | 10/18/02 | 3 | |
| | Entrap* | 10/18/02 | 27 | NR |
| | Fish entrainment | 10/18/02 | 0 | |
| | Fish entrapment | 10/18/02 | 0 | |
| | Fish impingement | 10/18/02 | 0 | |
| | Fish mortality AND cooling | 10/18/02 | 0 | |
| | water | 10/18/02 | 0 | |
| | Fish mortality AND imping* | 10/18/02 | 0 | |
| | Fish mortality AND power | 10/18/02 | | |
| | plants | 10/18/02 | 0 | |
| | Fish mortality AND water | 10/18/02 | | |
| | intake | 10/18/02 | 0 | |
| | Ichthyoplankton entrain* | 10/18/02 | 1 | 93 |
| | Ichthyoplankton entrap* | 10/18/02 | 0 | |
| | Ichthyoplankton imping* | 10/18/02 | 0 | |
| | Ichthyoplankton mortality | 10/18/02 | 0 | |
| | Imping* | 10/18/02 | 25 | NR |
| | Oil platform entrainment | 10/18/02 | 0 | |
| | Oil platform impact | 10/18/02 | 0 | |
| | Power plant entrainment | 10/18/02 | 0 | |
| | Power plant impact | 10/18/02 | 0 | |
| | Water-intake | 10/18/02 | 0 | |
| Catalog of U.S. Government | Cooling water | 11/06/02 | 200+ | NR |
| Publications | Cooling-water intake | 11/06/02 | 6 | NR |
| | Cooling-water entrain* | 11/06/02 | 3 | NR |
| | Cooling-water entrap* | 11/06/02 | 0 | |
| | Cooling-water imping* | 11/06/02 | 0 | |
| | Entrain* | 11/06/02 | 12 | 174 |
| | Fish AND entrain* | 11/06/02 | 2 | 175 |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Fish AND entrap* | 11/06/02 | 0 | |
| | Fish AND imping* | 11/06/02 | 0 | |
| | Fish mortality AND cooling water | 11/06/02 | 200+ | NR |
| | Fish mortality AND imping* | 11/06/02 | 0 | |
| | Fish mortality AND power plant* | 11/06/02 | 0 | |
| | Fish mortality AND water intake | 11/06/02 | 0 | |
| | Ichthyoplankton entrain* | 11/06/02 | 0 | |
| | Ichthyoplankton entrap* | 11/06/02 | 0 | |
| | Ichthyoplankton imping* | 11/06/02 | 0 | |
| | Ichthyoplankton mortality | 11/06/02 | 0 | |
| | Imping* | 11/06/02 | 22 | NR |
| | Oil platform AND entrain* | 11/06/02 | 0 | |
| | Oil platform AND impact | 11/06/02 | 1 | 176 |
| | Oil platform AND intake | 11/06/02 | 0 | |
| | Power plant AND entrain* | 11/06/02 | 2 | 177 |
| | Power plant AND entrap* | 11/06/02 | 0 | |
| | Power plant AND imping* | 11/06/02 | 1 | NR |
| | Power plant AND impact* | 11/06/02 | 96 | 178 |
| | Power plant AND intake* | 11/06/02 | 2 | 179 |
| | Water AND intake* | 11/06/02 | 11 | 180 |
| | Water AND intake* AND impact | 11/06/02 | 0 | |
| EIS: Digests of Environmental Impact Statements, including: Conference Papers Index | Cooling-water | 10/18/02 | 116 | 23 |
| | Cooling-water entrainment | 10/18/02 | 0 | |
| | Cooling-water entrapment | 10/18/02 | 0 | |
| | Cooling-water extraction | 10/18/02 | 1 | 22 |
| | Cooling-water impingement | 10/18/02 | 0 | |
| | Entrain* | 10/18/02 | 299 | NR |
| | Entrap* | 10/18/02 | 176 | NR |
| | Fish entrainment | 10/18/02 | 6 | 21 |
| | Fish entrapment | 10/18/02 | 1 | NR |
| | Fish impingement | 10/18/02 | 1 | 20 |
| | Fish mortality AND cooling water | 10/18/02 | 0 | |
| | Fish mortality AND imping* | 10/18/02 | 0 | |
| | Fish mortality AND power plants | 10/18/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Fish mortality AND water intake | 10/18/02 | 0 | |
| | Ichthyoplankton entrain* | | 1 | 19 |
| | Ichthyoplankton entrap* | 10/18/02 | 0 | |
| | Ichthyoplankton imping* | 10/18/02 | 0 | |
| | Ichthyoplankton mortality | 10/18/02 | 0 | |
| | Imping* | 10/18/02 | 221 | NR |
| | Oil platform entrainment | 10/18/02 | 0 | |
| | Oil platform entrapment | 10/18/02 | 0 | |
| | Oil platform impact | 10/18/02 | 0 | |
| | Oil platform intake | 10/18/02 | 0 | |
| | Power plant entrainment | 10/18/02 | 3 | 18 |
| | Power plant entrapment | 10/18/02 | 0 | |
| | Power plant impact | 10/18/02 | 0 | |
| | Power plant impingement | 10/18/02 | 0 | |
| | Water-intake | 10/18/02 | 62 | NR |
| | Water-intake impact | 10/18/02 | 1 | NR |
| ECO: Electronic Collections Online (OCLC First search) | Cooling water | 11/03/02 | 627 | NR |
| | Cooling-water | 11/03/02 | 5 | 104 |
| | Cooling-water impact | 11/03/02 | 0 | |
| | Cooling-water intake | 11/03/02 | 1 | NR |
| | Cooling-water mortality | 11/03/02 | 1 | NR |
| | Cooling-water entrainment | 11/03/02 | 0 | |
| | Cooling-water entrapment | 11/03/02 | 0 | |
| | Cooling-water impingement | 11/03/02 | 0 | |
| | Entrain* | 11/03/02 | 1144 | NR |
| | Fish entrain* | 11/03/02 | 39 | 105 |
| | Fish entrap* | 11/03/02 | 7 | 106 |
| | Fish imping* | 11/03/02 | 7 | 107 |
| | Fish mortality | 11/03/02 | 721 | NR |
| | Fish mortality AND cooling water | 11/03/02 | 1 | NR |
| | Fish mortality AND imping* | 11/03/02 | 2 | 108 |
| | Fish mortality AND power plants | 11/03/02 | 4 | 110 |
| | Fish mortality AND oil platform | 11/03/02 | 1 | 109 |
| | Fish mortality AND water intake | 11/03/02 | 6 | 111 |
| | Ichthyoplankton entrain* | 11/03/02 | 1 | 112 |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Ichthyoplankton entrap* | 11/03/02 | 0 | |
| | Ichthyoplankton imping* | 11/03/02 | 0 | |
| | Ichthyoplankton mortality | 11/03/02 | 5 | 113 |
| | Imping* AND mortality | 11/03/02 | 3 | 114 |
| | Imping* AND cooling-water | 11/03/02 | 0 | |
| | Imping* AND water intake | 11/03/02 | 3 | 115 |
| | Oil platform AND water intake | 11/03/02 | 1 | NR |
| | Oil platform AND entrain* | 11/03/02 | 1 | NR |
| | Oil platform AND entrap* | 11/03/02 | 1 | NR |
| | Oil platform AND imping* | 11/03/02 | 1 | NR |
| | Oil platform AND impact | 11/03/02 | 8 | 116 |
| | Oil platform AND intake | 11/03/02 | 1 | NR |
| | Power plant AND entrain* | 11/03/02 | 3 | NR |
| | Power plant AND entrap* | 11/03/02 | 2 | NR |
| | Power plant AND imping* | 11/03/02 | 3 | 117 |
| | Power plant AND intake | 11/03/02 | 3 | NR |
| | Water AND intake | 11/03/02 | 669 | NR |
| | Water-intake | 11/03/02 | 1 | NR |
| Expanded Academic ASAP (Info Trac) | Cooling-water* | 11/06/02 | 183 | NR |
| | Cooling-water entrain* | 11/06/02 | 1 | 181 |
| | Cooling-water entrap* | 11/06/02 | 1 | 182 |
| | Cooling-water imping* | 11/06/02 | 3 | 183 |
| | Entrain* | 11/06/02 | 0 | |
| | Fish AND entrain* | 11/06/02 | 8 | 185 |
| | Fish AND entrap* | 11/06/02 | 3 | 184 |
| | Fish AND imping* | 11/06/02 | 5 | 186 |
| | Fish mortality AND cooling water | 11/06/02 | 0 | |
| | Fish mortality AND imping* | 11/06/02 | 0 | |
| | Fish mortality AND power plant* | 11/06/02 | 0 | |
| | Fish mortality AND water intake | 11/06/02 | 0 | |
| | Ichthyoplankton entrain* | 11/06/02 | 1 | 187 |
| | Ichthyoplankton entrap* | 11/06/02 | 0 | |
| | Ichthyoplankton imping* | 11/06/02 | 1 | 188 |
| | Ichthyoplankton mortality | 11/06/02 | 2 | 189 |
| | Imping* | 11/06/02 | 827 | NR |
| | Oil platform AND entrain* | 11/06/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Oil platform AND impact | 11/06/02 | 1 | 190 |
| | Oil platform AND intake | 11/06/02 | 0 | |
| | Power plant AND entrain* | 11/06/02 | 8 | 191 |
| | Power plant AND entrap* | 11/06/02 | 2 | 192 |
| | Power plant AND imping* | 11/06/02 | 5 | 193 |
| | Power plant AND impact* | 11/06/02 | 196 | NR |
| | Power plant AND intake* | 11/06/02 | 20 | 194 |
| | Water-intake* | 11/06/02 | 236 | NR |
| | Water AND intake* | 11/06/02 | 779 | NR |
| | Water AND intake* AND impact | 11/06/02 | 20 | 195 |
| JSTOR | Cooling water | 10/28/02 | 121 | NR |
| | Cooling-water impact | 10/28/02 | 0 | |
| | Cooling-water intake | 10/28/02 | 7 | 94 |
| | Cooling-water mortality | 10/28/02 | 0 | |
| | Cooling-water entrainment | 10/28/02 | 0 | |
| | Cooling-water entrapment | 10/28/02 | 0 | |
| | Cooling-water impingement | 10/28/02 | 0 | |
| | Entrain* | 10/28/02 | 127 | NR |
| | Fish AND entrain* | 10/28/02 | 60 | NR |
| | Fish AND entrap* | 10/28/02 | 28 | 102 |
| | Fish AND impingement | 10/28/02 | 19 | 101 |
| | Fish entrainment | 10/28/02 | 0 | |
| | Fish entrapment | 10/28/02 | 1 | 95 |
| | Fish imping* | 10/28/02 | 0 | |
| | Fish impingement | 10/28/02 | 2 | 96 |
| | Fish mortality AND cooling water | 10/28/0 | 1 | 97 |
| | Fish mortality AND impingement | 10/28/02 | 1 | 98 |
| | Fish mortality AND power plant* | 10/28/02 | 1 | 99 |
| | Fish mortality AND oil platform | 10/28/02 | 0 | |
| | Fish mortality AND water intake | 10/28/02 | 3 | 100 |
| | Ichthyoplankton entrain* | 10/28/02 | 0 | |
| | Ichthyoplankton entrap* | 10/28/02 | 0 | |
| | Ichthyoplankton imping* | 10/28/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Ichthyoplankton mortality | 10/28/02 | 0 | |
| | Imping* AND mortality | 10/28/02 | 0 | |
| | Imping* AND cooling-water | 10/28/02 | 0 | |
| | Imping* AND water intake | 10/28/02 | 0 | |
| | Oil platform AND water intake | 10/28/02 | 0 | |
| | Oil platform AND cooling-water | 10/28/02 | 0 | |
| | Oil platform AND entrain* | 10/28/02 | 0 | |
| | Oil platform AND entrap* | 10/28/02 | 0 | |
| | Oil platform AND impact | 10/28/02 | 5 | NR |
| | Oil platform AND intake | 10/28/02 | 0 | |
| | Power plant AND entrain* | 10/28/02 | 4 | NR |
| | Power plant AND entrap* | 10/28/02 | 1 | NR |
| | Power plant AND imping* | 10/28/02 | 26 | 103 |
| | Power plant AND intake | 10/28/02 | 0 | |
| Science Citation Index (Web of Knowledge/Web of Science) | Cooling water | 11/05/02 | 1176 | NR |
| | Cooling-water AND impact | 11/05/02 | 0 | |
| | Cooling-water AND entrain* | 11/05/02 | 1 | 162 |
| | Cooling-water AND entrap* | 11/05/02 | 0 | |
| | Cooling-water AND imping* | 11/05/02 | 0 | |
| | Entrain* | 11/05/02 | 11411 | NR |
| | Fish entrain* | 11/05/02 | 10 | 163 |
| | Fish entrap* | 11/05/02 | 4 | 164 |
| | Fish imping* | 11/05/02 | 8 | 165 |
| | Fish impingement | 11/05/02 | 8 | 17 |
| | Fish mortality AND cooling water | 11/05/02 | 1 | 166 |
| | Fish mortality AND imping* | 11/05/02 | 0 | |
| | Fish mortality AND power plant | 11/05/02 | 2 | 167 |
| | Fish mortality AND oil platform | 11/05/02 | 0 | |
| | Fish mortality AND water intake | 11/05/02 | 0 | |
| | Ichthyoplankton & entrain* | 11/05/02 | 3 | 168 |
| | Ichthyoplankton & entrap* | 11/05/02 | 0 | |
| | Ichthyoplankton & imping* | 11/05/02 | 0 | |
| | Ichthyoplankton & mortality | 11/05/02 | 4 | 169 |
| | Oil platform AND entrain* | 11/05/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Oil platform AND entrap* | 11/05/02 | 0 | |
| | Oil platform AND imping* | 11/05/02 | 0 | |
| | Oil platform AND intake | 11/05/02 | 0 | |
| | Power plant AND entrain* | 11/05/02 | 11 | 170 |
| | Power plant AND entrap* | 11/05/02 | 0 | |
| | Power plant AND imping* | 11/05/02 | 0 | |
| | Power plant AND intake | 11/05/02 | 3 | 172 |
| | Power plant AND impact | 11/05/02 | 8 | 171 |
| | Water-intake | 11/05/02 | 2857 | NR |
| | Water-intake entrain* | 11/05/02 | 1 | 173 |
| | Water-intake imping* | 11/05/02 | 0 | |
| | Water-intake impact | 11/05/02 | 0 | |
| Springer Interlink | Cooling-water | 11/04/02 | 7 | NR |
| (Environmental Sciences) | Cooling-water AND impact | 11/04/02 | 55 | NR |
| | Cooling-water AND imping* | 11/04/02 | 1 | NR |
| | Cooling-water AND intake | 11/04/02 | 11 | NR |
| | Cooling-water AND mortality | 11/04/02 | 13 | NR |
| | Cooling-water AND entrain* | 11/04/02 | 11 | NR |
| | Cooling-water AND entrap* | 11/04/02 | 7 | NR |
| | Cooling-water AND imping* | 11/04/02 | 7 | NR |
| | Entrain* | 11/04/02 | 1428 | NR |
| | Fish entrain* | 11/04/02 | 0 | |
| | Fish AND entrain* | 11/04/02 | 37 | NR |
| | Fish imping* | 11/04/02 | 0 | |
| | Fish mortality AND entrap* | 11/04/02 | 2 | NR |
| | Fish mortality AND imping* | 11/04/02 | 11 | NR |
| | Fish mortality AND oil platform | 11/04/02 | 0 | NR |
| | Ichthyoplankton & entrain* | 11/04/02 | 1 | 158 |
| | Ichthyoplankton & entrap* | 11/04/02 | 1 | NR |
| | Ichthyoplankton & imping* | 11/04/02 | 1 | NR |
| | Ichthyoplankton & mortality | 11/04/02 | 3 | NR |
| | Imping* | 11/04/02 | 142 | NR |
| | Imping* AND fish | 11/04/02 | 24 | NR |
| | Oil platform AND imping* | 11/04/02 | 0 | |
| | Power plant AND entrain* | 11/04/02 | 0 | |
| | Power plant AND entrap* | 11/04/02 | 0 | |
| | Power plant AND imping* | 11/04/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| Wildlife and Ecology Studies Worldwide | Cooling-water | 11/05/02 | 158 | NR |
| | Cooling-water AND entrain* | 11/05/02 | 0 | |
| | Cooling-water AND entrap* | 11/05/02 | 0 | |
| | Imping* | 11/05/02 | 26 | NR |
| | Fish AND imping* | 11/05/02 | 3 | 159 |
| | Fish AND entrain* | 11/05/02 | 4 | 160 |
| | Fish AND entrap* | 11/05/02 | 15 | NR |
| | Fish mortality AND entrap* | 11/05/02 | 12 | NR |
| | Fish mortality AND intake | 11/05/02 | 3 | NR |
| | Ichthyoplankton & entrain* | 11/05/02 | 0 | |
| | Ichthyoplankton & entrap* | 11/05/02 | 1 | 161 |
| | Ichthyoplankton & imping* | 11/05/02 | 0 | |
| World Cat (OCLC First search) | Cooling-water | 11/03/02 | 30 | 118 |
| | Cooling-water AND impact | 11/03/02 | 0 | |
| | Cooling-water AND intake | 11/03/02 | 2 | 119 |
| | Cooling-water AND mortality | 11/03/02 | 0 | |
| | Cooling-water AND entrain* | 11/03/02 | 0 | |
| | Cooling-water AND entrap* | 11/03/02 | 0 | |
| | Cooling-water AND imping* | 11/03/02 | 1 | 120 |
| | Entrain* | 11/03/02 | 3359 | NR |
| | Fish entrain* | 11/03/02 | 89 | 121 |
| | Fish entrap* | 11/03/02 | 14 | 122 |
| | Fish imping* | 11/03/02 | 54 | 123 |
| | Fish mortality AND cooling water | 11/03/02 | 0 | |
| | Fish mortality AND entrain* | 11/03/02 | 19 | 125 |
| | Fish mortality AND entrap* | 11/03/02 | 1 | 126 |
| | Fish mortality AND imping* | 11/03/02 | 7 | 124 |
| | Fish mortality AND power plant | 11/03/02 | 19 | 127 |
| | Fish mortality AND oil platform | 11/03/02 | 0 | |
| | Fish mortality AND water intake | 11/03/02 | 0 | |
| | Ichthyoplankton & entrain* | 11/03/02 | 16 | 128 |
| | Ichthyoplankton & entrap* | 11/03/02 | 0 | |
| | Ichthyoplankton & imping* | 11/03/02 | 3 | 129 |
| | Ichthyoplankton & mortality | 11/03/02 | 9 | 130 |
| | Imping* AND mortality | 11/03/02 | 15 | 131 |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Imping* AND cooling-water | 11/03/02 | 1 | 132 |
| | Imping* AND water intake | 11/03/02 | 5 | 133 |
| | Oil platform AND water intake | 11/03/02 | 0 | |
| | Oil platform AND entrain* | 11/03/02 | 0 | |
| | Oil platform AND entrap* | 11/03/02 | 0 | |
| | Oil platform AND imping* | 11/03/02 | 0 | |
| | Oil platform AND impact | 11/03/02 | 13 | 134 |
| | Oil platform AND intake | 11/03/02 | 0 | |
| | Power plant AND entrain* | 11/03/02 | 89 | 135 |
| | Power plant AND entrap* | 11/03/02 | 1 | 136 |
| | Power plant AND imping* | 11/03/02 | 46 | 137 |
| | Power plant AND intake | 11/03/02 | 91 | 138 |
| | Power plant AND water intake | 11/03/02 | 45 | 139 |
| | Water AND intake | 11/03/02 | 634 | NR |
| | Water-intake | | 6 | NR |
| Zoological Record | Cooling-water | 11/03/02 | 8 | 140 |
| | Cooling-water AND impact | 11/03/02 | 0 | |
| | Cooling-water AND intake | 11/03/02 | 4 | 141 |
| | Cooling-water AND mortality | 11/03/02 | 0 | |
| | Cooling-water AND entrain* | 11/03/02 | 0 | |
| | Cooling-water AND entrap* | 11/03/02 | 0 | |
| | Cooling-water AND imping* | 11/03/02 | 0 | |
| | Entrain* | 11/03/02 | 336 | NR |
| | Fish entrain* | 11/03/02 | 8 | 142 |
| | Fish entrap* | 11/03/02 | 12 | 143 |
| | Fish imping* | 11/03/02 | 6 | 144 |
| | Fish mortality AND cooling water | 11/03/02 | 0 | |
| | Fish mortality AND entrain* | 11/03/02 | 0 | |
| | Fish mortality AND entrap* | 11/03/02 | 5 | 145 |
| | Fish mortality AND imping* | 11/03/02 | 0 | |
| | Fish mortality AND power plant | 11/03/02 | 0 | |
| | Fish mortality AND oil platform | 11/03/02 | 0 | |
| | Fish mortality AND water intake | 11/03/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Ichthyoplankton & entrain* | 11/03/02 | 5 | 146 |
| | Ichthyoplankton & entrap* | 11/03/02 | 0 | |
| | Ichthyoplankton & imping* | 11/03/02 | 0 | |
| | Ichthyoplankton & mortality | 11/03/02 | 2 | 147 |
| | Imping* AND mortality | 11/03/02 | 15 | 148 |
| | Imping* AND cooling-water | 11/03/02 | 1 | 149 |
| | Imping* AND water intake | 11/03/02 | 8 | 150 |
| | Oil platform AND water intake | 11/03/02 | 0 | |
| | Oil platform AND entrain* | 11/03/02 | 0 | |
| | Oil platform AND entrap* | 11/03/02 | 0 | |
| | Oil platform AND imping* | 11/03/02 | 0 | |
| | Oil platform AND impact | 11/03/02 | 1 | 151 |
| | Oil platform AND intake | 11/03/02 | 0 | |
| | Power plant AND entrain* | 11/03/02 | 57 | 152 |
| | Power plant AND entrap* | 11/03/02 | 2 | 153 |
| | Power plant AND imping* | 11/03/02 | 15 | 154 |
| | Power plant AND intake | 11/03/02 | 20 | 155 |
| | Power plant AND water intake | 11/03/02 | 11 | 156 |
| | Water AND intake | 11/03/02 | 337 | NR |
| | Water-intake | | 22 | 157 |
| Oceanic Abstracts (CSA) | Cooling-water entrainment | 10/18/02 | 0 | |
| | Cooling-water entrapment | 10/18/02 | 0 | |
| | Cooling-water impingement | 10/18/02 | 1 | 33 |
| | Entrain* | 10/18/02 | | |
| | Entrained | 10/18/02 | 380 | NR |
| | Entraining | 10/18/02 | 65 | NR |
| | Entrap* | 10/18/02 | 169 | NR |
| | Entrapped | 10/18/02 | 63 | NR |
| | Fish entrainment | 10/18/02 | 1 | 32 |
| | Fish entrapment | 10/18/02 | | |
| | Fish impingement | 10/18/02 | | |
| | Fish mortality AND cooling water | 10/18/02 10/18/02 | 1 | 31 |
| | Fish mortality AND imping* | 10/18/02 | 1 | 30 |
| | Fish mortality AND power plants | 10/18/02 10/18/02 | 1 | 29 |
| | Fish mortality AND water intake | 10/18/02 10/18/02 | 0 | |

Table 2.

Searched Databases and Key Words with Date, Number of Results Per Query, and File Number for Each Output (NR = not recorded) (continued).

| Database Title | Key Word | Date | Results | File |
|---|---|---|---|---|
| | Ichthyoplankton entrain* | 10/18/02 | 1 | 28 |
| | Ichthyoplankton entrap* | 10/18/02 | 0 | |
| | Ichthyoplankton imping* | 10/18/02 | 0 | |
| | Ichthyoplankton mortality | 10/18/02 | 1 | NR |
| | Imping* | 10/18/02 | 236 | NR |
| | Oil platform entrainment | 10/18/02 | 0 | |
| | Oil platform entrapment | 10/18/02 | 0 | |
| | Oil platform impact | 10/18/02 | 0 | |
| | Oil platform intake | 10/18/02 | 0 | |
| | Power plant entrainment | 10/18/02 | 5 | 27 |
| | Power plant entrapment | 10/18/02 | 0 | |
| | Power plant impact | 10/18/02 | 0 | |
| | Power plant impingement | 10/18/02 | 1 | 26 |
| | Water-intake | 10/18/02 | 61 | 25 |
| | Water-intake impact | 10/18/02 | 0 | |

## RESULTS

A total of 342 references are presented in this report in four different categories: 138 are references on biological studies directly related to fish impingement or entrainment by cooling-water intake systems in marine and estuarine environments; 74 are references on mathematical models to assess fish impingement or entrainment by cooling-water intake systems, 59 are references related to mitigation measures for fish impingement or entrainment, and 71 are other relevant references on fish impingement or entrainment by cooling-water intake systems or closely related topics.

Most of the results obtained through this search were references about studies on fish impingement or entrainment by cooling-water intakes of nuclear or thermoelectric power plants located on estuarine or marine environments. Only one reference specific to fish impingement or entrainment by cooling-water intakes of oil platforms, Littrell and Biaggi (1979), was actually found, which means that such information is generally unavailable through the searched data bases. However, it is possible that some information exists in unpublished corporate documents.

A total of 95 fish species were found in the abstracts, including 53 species found in U.S. waters (AFS 1991) and 10 species confirmed in the northern Gulf of Mexico (Hoese and Moore 1998). The results are presented in Table 3; however, some abstracts just mention a few of the fish species subject to impingement or entrainment and some others give only the number of fish species with the actual list of fish names located inside the document. For example, Araujo *et al.* (1998) mention 15 species, Koehler (1981) mentions 22 species, Love *et al*. (1998) mention 16 species, Maes *et al.* (1998) mention 55 species, Reay and Culley (1980) mention 100 species, and Shao *et al.* (1990) mention 295 species. For a more complete list of fish species subject to impingement or entrainment, it would be necessary to acquire and analyze the complete documents.

Table 3.

List of Scientific and Common Names of Fish Species Found in Abstracts, Their Maximum Length Attained, and Occurrence (A = Atlantic, F = Freshwater, I = Indian, P = Pacific, * = Present in U. S. waters, ** = Confirmed in the northern Gulf of Mexico)

| Scientific Name | Common Name | Max. Length (cm) | Occurrence |
|---|---|---|---|
| *Abudefduf septemfasciatus* | Seven-bar damsel | 23 | I-P |
| *Agonus cataphractus* | Hooknose | 21 | A |
| *Alosa aestivalis* | Blue-back herring | 28 | A-F* |
| *Alosa alosa* | Shad | 70 | A |
| *Alosa chrysochloris* | Skipjack herring | 46 | A-F** |
| *Alosa fallax* | Twaite shad | 50 | A |
| *Alosa pseudoharengus* | Alewife | 40 | A-F* |
| *Alosa sapidissima* | American shad | 51 | A-F-P* |
| *Ammodytes tobianus* | Sand lance | 20 | A |
| *Anchoa mitchilli* | Bay anchovy | 10 | A-F** |
| *Anguilla anguilla* | European eel | 100 | A |
| *Aplodinotus grunniens* | Freshwater drum | 95 | F* |
| *Atherina presbyter* | Sand smelt | 20 | A |
| *Brevoortia tyrannus* | Atlantic menhaden | 35 | A* |
| *Ciliata mustela* | Five-bearded rockling | 17 | A |
| *Clupea harengus harengus* | Atlantic herring | 40 | A* |
| *Crenimugil labrosus* | Thicklip grey mullet | 60 | A |
| *Cyclopterus lumpus* | Lumpfish | 61 | A* |
| *Cymatogaster aggregata* | Shiner surfperch | 18 | P-F* |
| *Dicentrarchus labrax* | European sea bass | 100 | A |
| *Dorosoma cepedianum* | Gizzard shad | 30 | A-F** |
| *Dorosoma petenense* | Threadfin shad | 18 | A-F-P** |
| *Engraulis mordax* | Northern anchovy | 18 | P* |
| *Entelurus aequoreus* | Snake pipefish | 60 | A |
| *Gadus morhua* | Atlantic cod | 104 | A* |
| *Gasterosteus aculeatus* | Three-spine stickleback | 8 | A-F-P* |
| *Genyonemus lineatus* | White croaker | 41 | P |
| *Gobiosoma bosci* | Naked goby | 6 | A-F** |
| *Gymnocephalus cernuus* | Ruffe | 25 | F* |
| *Hyperoplus lanceolatus* | Greater sand-eel | 40 | A |
| *Hyperprosopon argenteum* | Walleye surfperch | 30 | P* |
| *Lagocephalus inermis* | Smooth blaasop | 90 | I-P |
| *Lagodon rhomboides* | Pinfish | 40 | A-F** |
| *Lampetra fluviatilis* | River lamprey | 45 | A |

Table 3.

List of Scientific and Common Names of Fish Species Found in Abstracts, Their Maximum Length Attained, and Occurrence (A = Atlantic, F = Freshwater, I = Indian, P = Pacific, * = Present in U. S. waters, ** = Confirmed in the northern Gulf of Mexico) (continued).

| Scientific Name | Common Name | Max. Length (cm) | Occurrence |
|---|---|---|---|
| *Leiostomus xanthurus* | Spot | 25 | A-F** |
| *Lepomis gibbosus* | Pumpkinseed | 30 | F* |
| *Limanda limanda* | Dab | 40 | A |
| *Liopsetta putnami* | Smooth flounder | 30 | A* |
| *Liparis liparis* | Stripped seasnail | 15 | A* |
| *Liparis montagui* | Snailfish | 51 | A |
| *Lota lota* | Burbot | 50 | F* |
| *Merlangius merlangus* | Whiting | 70 | A |
| *Microgadus tomcod* | Atlantic tomcod | 38 | A-F* |
| *Morone americana* | White perch | 48 | A-F* |
| *Morone saxatilis* | Striped bass | 125 | A-F-P** |
| *Mugil cephalus* | Striped mullet | 76 | A-F-P** |
| *Mullus surmuletus* | Red mullet | 40 | A |
| *Myoxocephalus scorpius* | Arctic sculpin | 60 | A-P* |
| *Oncorhynchus tshawytscha* | Chinook salmon | 147 | P-F* |
| *Osmerus eperlanus* | Estuarine smelt | 45 | A |
| *Osmerus mordax* | Rainbow smelt | 13 | A-F-P* |
| *Peprilus simillimus* | Pacific pompano | 28 | P* |
| *Perca flavescens* | Yellow perch | 29 | F* |
| *Phanerodon furcatus* | White surfperch | 32 | P* |
| *Pholis gunnellus* | Rock gunnel | 25 | A* |
| *Platichthys flesus* | Flounder | 50 | A |
| *Pleuronectes platessa* | Plaice | 100 | A |
| *Pollachius virens* | Pollock | 120 | A* |
| *Pomatoschistus lozanoi* | Lozano's goby | 8 | A |
| *Pomatoschistus microps* | Common goby | 6 | A |
| *Pomatoschistus minutus* | Sand goby | 10 | A |
| *Pomatoschistus pictus* | Painted goby | 6 | A |
| *Prionotus carolinus* | Northern searobin | 41 | A** |
| *Prionotus evolans* | Stripped searobin | 45 | A* |
| *Pseudopleuronectes americanus* | Winter flounder | 64 | A* |
| *Raniceps raninus* | Tadpole-fish | 30 | A |
| *Rutilus rutilus* | Roach | 46 | F |
| *Salmo salar* | Atlantic salmon | 150 | A-F* |

Table 3.

List of Scientific and Common Names of Fish Species Found in Abstracts, Their Maximum Length Attained, and Occurrence (A = Atlantic, F = Freshwater, I = Indian, P = Pacific, * = Present in U. S. waters, ** = Confirmed in the northern Gulf of Mexico) (continued).

| Scientific Name | Common Name | Max. Length (cm) | Occurrence |
|---|---|---|---|
| *Salmo trutta* | Sea trout | 50 | A-F* |
| *Sardinella sindensis* | Sind sardine | 17 | I |
| *Sebastes auriculatus* | Brown rockfish | 55 | P* |
| *Sebastes mystinus* | Blue rockfish | 53 | P* |
| *Sebastes paucispinis* | Bocaccio | 91 | P* |
| *Sebastes rastrelliger* | Grass rockfish | 56 | P* |
| *Sebastes serranoides* | Olive rockfish | 61 | P* |
| *Sebastes serriceps* | Treefish | 41 | P* |
| *Seriphus politus* | Queenfish | 30 | P* |
| *Solea solea* | Common sole | 70 | A |
| *Sparus aurata* | Gilthead sea bream | 70 | A |
| *Spinachia spinachia* | Fifteen-spined stickleback | 22 | A |
| *Sprattus sprattus* | Sprat | 16 | A |
| *Stizostedion canadense* | Sauger | 76 | F* |
| *Stizostedion vitreum* | Walleye | 107 | F* |
| *Syngnathus acus* | Greater pipefish | 50 | A-I |
| *Syngnathus rostelattus* | Nilsson's pipefish | 17 | A |
| *Taurulus bubalis* | Sea scorpion | 18 | A |
| *Tautogolabrus adspersus* | Cunner | 38 | A* |
| *Therapon puta* | Spiny-cheeked grunt | 15 | A |
| *Trachinus vipera* | Leeser weever | 15 | A |
| *Triglopsis thompsonii* | Deepwater sculpin | 23 | F* |
| *Trisopterus luscus* | Pout | 45 | A |
| *Trisopterus minutus* | Poor cod | 26 | A |
| *Urophycis chuss* | Red hake | 130 | A* |
| *Zoarces viviparus* | Viviparous eelpout | 52 | A |

## COMMENTS

The ecological impact of oil platform water intakes might be different than those for power plants mainly because of the offshore location of most oil platforms, the large number of them, and the differences in volume of cooling water required at each oil platform. For example, Kindt (1980) mentions that each nuclear power plant requires approximately10 million gallons of cooling water per minute, an amount much higher than that required by oil platforms.

## PART I: STUDIES OF FISH IMPINGEMENT/ENTRAINMENT BY COOLING-WATER INTAKES IN MARINE AND ESTUARINE ENVIRONMENTS

Abou-Seedo, F. S. and I. C. Potter. 1979. The estuarine phase in the spawning run of the river lamprey *Lampetra fluviatilis*. J. Zool., Vol. 188, No. 1, pp. 5-25.

Abstract: The biology of the very early stages in the upstream migration of the river lamprey has been studied using samples taken from the cooling-water intake screens of the Oldbury Power Station in the Severn Estuary. An increase in freshwater discharge is the predominant environmental factor responsible for initiating the movement from the sea into the estuary, although temperature may also be a contributory factor. The migrants could be separated into typical and praecox forms whose mean lengths during peak abundance were approximately 300 and 240 mm respectively. The typical forms were found in the estuary between July and April, with peak abundance in November, whereas the praecox forms were present mainly between January and March. The ratio of typical to praecox forms over the four years of sampling was estimated as 3.3:1. Measurement of a number of different characters suggest that, although the typical forms enter the estuary over a long period of time, the onset of the changes leading to sexual maturity are more synchronous. Measurements made on typical animals from Oldbury in November indicate that they can regulate their plasma ions in salinities as high as 70% of full strength sea water.

Ambrogi, R. and R. Vitali. 1992. Environmental impact assessment for Italian thermoelectric power plants in coastal zones. Bulletin de l'Institut Oceanographique, Monaco. Monaco, Vol. 51, No. 11, pp 289-298.

Abstract: Environmental impact studies on coastal marine power stations take into account both the effects on marine organisms passing through the plant, and environmental effects at the warm water discharge site. A synthesis is presented of the research carried out on an open-sea power station (Brindisi) and on an estuarine one (Porto Tolle).

Anon. 1973. Entrainment studies. Marine ecology studies related to operation of Pilgrim Station. Semi-annual report No. 2. [Marine ecology studies related to operation of Pilgrim Station Semi-annual report (series)].

Abstract: Actual data collection for this study did not commence until Aug. 1973, consequently no results are available for reporting here. Sampling procedures and techniques being employed for these studies have been further developed and are described. Measurements are being conducted initially over a period of 1 yr to determine the effects of cooling-water entrainment on phytoplankton, zooplankton, fish eggs, fish larvae, and lobster larvae. Samples of these organisms will be collected at the intake canal just ahead of the intake screens, and in the discharge canal.

Anon. 1974. Selected references on the ichthyoplankton of the CICAR area. Compiled for the Ichthyoplankton Workshop held in the Mexico Oceanic Sorting Centre (Mexico, D.F., 17-26 July 1974). Bol. Tec. CPOM/CPOM Tech. Pap., No. 1., Sep 1974.

Abstract: The selected references prepared by some of the participants to the CICAR Ichthyoplankton Workshop on Fish Egg and Larval Studies of the Caribbean Area have been compiled in the present bibliography. It includes 366 references mainly dealing with identification of eggs and/or larvae of several fish families, including those of economic importance, as Clupeidae, Engraulidae, Gadidae, Carangidae. Useful references on quantitative sampling of ichthyoplankton are also included as well as a list of references on power plant entrainment. An author index is also given.

Anon. 1982. Marine ichthyoplankton entrainment studies. California: Southern California Edison Co.

Applied Marine Research Limited. 1974. Biological field program conducted as a component of a nuclear power plant intake study in New Brunswick. Halifax.

Araujo, F. G., R. G. Bailey and W. P. Williams. 1998. Seasonal and between-year variations of fish populations in the middle Thames estuary: 1980-1989. Fisheries Management and Ecology, Vol. 5, No. 1, (Feb. 1998), pp. 1-21.

Abstract: (1) Fish samples collected at the cooling-water intake screens of West Thurrock power station located 35.5 km downstream of London Bridge on the Thames estuary during the decade 1980-1989 were analyzed. (2) Seasonal and long-term changes in the abundance of the 15 most numerous fish species and in several fish community parameters were analyzed. (3) The majority of species were highly seasonal in their distribution and abundance. Species diversity was lower in the summer (May-August) compared with spring/winter (October-February). (4) Evidence of long-term changes in species diversity and community structure over the decade is presented. The changes were consistent with a period of relative stability (1980-1984) followed by a period of change (1985-1989) and may reflect a deterioration in water quality in the second quinquennium. (5) It is argued that the monitoring of fish communities in estuaries should be based on a multi-metric approach as no single indicator alone can describe the complex community structure.

Araujo, F. G., W. P. Williams and R. G. Bailey. 2000. Fish Assemblages as Indicators of Water Quality in the Middle Thames Estuary, England (1980-1989). Estuaries, Vol. 23, No. 3, (Jun. 2000), pp. 305-317.

Abstract. (1) Fish abundance and environmental data collected over ten years (1980-1989) from the Middle Thames estuary, England, were analyzed to detect temporal trends in fish populations and relationship with environmental parameters, and to assess water quality. Fish were collected from the cooling-water intake screens of West Thurrock power station, situated 35.5 km below London Bridge, in the mid-estuary. (2) Marine species abundance were highly seasonal, with peaks in December-March for herring (*Clupea harengus*), sprat (*Sprattus sprattus*), 3-spined-stickleback (*Gasterosteus aculeatus*), and poor cod (*Trisopterus minutus*); July-August for flounder (*Platichthys flesus*); and September-December for sand goby (*Pomatoschistus minutus*), whiting (*Merlangius merlangus*), bass (*Dicentrarchus labrax*), plaice (*Pleuronectes platessa*), and dab (*Limanda limanda*). (3) Bimodal seasonal patterns of peaks or unclear seasonality in abundance characterized marine estuarine-dependent sole (*Solea solea*),

Nilsson's pipefish (*Syngnathus rostelattus*) (April/May and September/October), and pouting (*Trisopterus luscus*) (May and November/December); the estuarine smelt (*Osmerus eperlanus*) (October and January) and the catadromous eel (*Anguilla anguilla*) (June and October). (4) There was substantial variation in the abundance of common species over the period of ten years, with herring, sand goby, flounder, and plaice showing a stable abundance in 1980-1984, increasing sharply in 1985-1986, and then decreasing successively through the remainder of the decade (1987-1989). The first half of the decade was a period of higher abundance for less tolerant species such as smelt, sprat, and poor cod, while the second half showed higher abundances of species tolerant to harsh environmental conditions such as sand goby, flounder, eel, and plaice. (5) A general pattern of stable fish populations with a slight trend of deterioration was found to emerge over the years, related to the number of species and quantities of common species. Multivariate techniques of principal component and canonical correspondence ordinations were used for assessing relationships between fish populations abundance and environmental variables. (6) The most significant environmental variables correlated with fish species were temperature and dissolved oxygen. High abundances of flounder were associated with high temperature, while high abundance of poor cod, sprat, herring, and 3-spined-stickleback were associated with high dissolved oxygen, flow, ammoniacal nitrogen, and low temperature. Plaice, whiting, sand goby, bass, and dab were preferentially found in high salinity and suspended solids, while smelt and sole were likely to prefer average values or showed no clear preferences.

Barker, S. L., D. W. Townsend and J. S. Hacunda. 1981. Mortalities of Atlantic Herring, *Clupea h. harengus*, Smooth Flounder, *Liopsetta putnami*, and Rainbow Smelt, *Osmerus mordax*, Larvae Exposed to Acute Thermal Shock. Fishery Bulletin, Vol. 79, No. 1, pp. 198-200.

Abstract: Experiments were designed to evaluate the thermal tolerances of three species of larval fish occurring in the Gulf of Maine and its estuaries: Atlantic herring, *Clupea h. harengus*, smooth flounder, *Liopsetta putnami*, and rainbow smelt, *Osmerus mordax*. These fish, although differing somewhat in their life histories, are all common in inshore areas during some part of their larval life, and are therefore subject to power plant entrainment. This paper presents the results of thermal tolerance experiments, which encompassed the range of temperatures planktonic organisms encounter in condenser cooling systems.

Barnes, J. M. 1977. The sustained swimming ability of larval and juvenile gizzard shad, *Dorosoma cepedianum* (LeSueur), and threadfin shad, *D. petenense* (Gunther), as related to entrainment and/or impingement by water intake structures of power stations.

Beauchamp J. J. and K. D. Kumar. 1984. Sub-sampling program for the estimation of fish impingement. Environmental Management, Vol. 8, Iss. 6, pp 539-542.

Benda, R. S. 1982. Diurnal movement of fish larvae and invertebrates into a power plant intake. Proceedings of the Indiana Academy of Science. Vol. 91, pp. 601-605.

Boreman, J. 1977. Impacts of power plant intake velocities on fish. Ann Arbor, Mich.: Power Plant Project, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior.

Boreman, J. 1981-1982. The Impact of entrainment and impingement of fish populations in the Hudson River estuary. Washington, D.C: Springfield, Va.: The Commission: Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission; National Technical Information Service,

Bowles, R. R. 1978. Factors affecting accuracy of ichthyoplankton samples used in power plant entrainment studies. Washington: Fish and Wildlife Service, U.S. Dept. of the Interior.

Bridges, W. L. and R. D. Anderson. 1984. A brief survey of Pilgrim Nuclear Power Plant effects upon the marine aquatic environment. Observations on the Ecology and Biology of Western Cape Cod Bay, Massachusetts, Lect. Notes Coast. Estuar. Stud., Vol. 11, pp. 263-271.

Abstract: A broad range of environmental studies, begun in 1969, were designed to detect environmental disturbances attributable to release of heated cooling water into Cape Cod Bay from the Pilgrim Nuclear Power Station. On a scale encompassing the more immediate vicinity of the power station certain site specific or occasionally occurring effects were documented. Most notable were several significant mortalities due to "gas bubble disease", periodic incidences of finfish impingement on the cooling-water intake traveling screens, near-field alterations of the benthic and epibenthic communities in the vicinity of the cooling-water discharge, and entrainment of phytoplankton, zooplankton, and ichthyoplankton in the cooling-water flow.

Brooks, A. J., R. J. Schmitt and S. J. Holbrook. 2002. Declines in regional fish populations: have species responded similarly to environmental change? Marine and Freshwater Research, Vol. 53, No. 2, pp. 189-

Cada, G. F. and G. L. Hergenrader. 1978. An assessment of sampling mortality of larval fishes. Transactions of the American Fisheries Society. Vol. 107, No. 2, pp. 269-274.

Campbell, K. P., I. R. Savidge, W. P. Dey and J. B. McLaren. 1977. Impacts of recent power plants on the Hudson River striped bass (*Morone saxatilis*) population. In: Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 3-6, 1977.

Abstract: The impact of the Bowline, Roseton, and Indian Point power plants has been studied by estimating entrainment and impingement mortality rates on striped bass at these plants and relating these mortality rates to reduction in equilibrium stock size under various hypothetical stock-recruitment relationships. The conditional rates of mortality due to entrainment by these three plants were 0.0811 in 1974 and 0.1188 in 1975. The conditional rates of mortality due to impingement were calculated to be 0.0426 in 1974 and 0.0229 in 1975. Based on a range of potential Ricker stock-recruitment curves, reduction in equilibrium stock size due to the estimated levels of power-plant-induced mortality were discussed.

Carpenter, E. J., S. J. Anderson and B. B. Peck. 1971. First semi-annual report on entrainment of marine plankton through Millstone Unit One: to Northeast Utilities Service Co. Woods Hole, Mass.: Woods Hole Oceanographic Institution.

Carpenter, E. J., S. J. Anderson and B. B. Peck. 1971. Second semi-annual report on entrainment of marine plankton through Millstone Unit One: to Northeast Utilities Service Co. Woods Hole, Mass.: Woods Hole Oceanographic Institution.

Chase, D. M. and K. Strawn. 1978. Survival rates of fishes and macroinvertebrates impinged on the vertically revolving intake screens of a power plant on Galveston Bay, Texas. Houston, Tex.: Houston Lighting & Power Company.

Chow, W., I. P. Murarka and R. W. Brocksen. 1981. Entrainment and impingement in power plant cooling systems. Journal Water Pollution Control Federation, Vol. 53, No. 6, pp. 965-973.

Chung, K-S. 1977. Heat resistance of crustaceans and fishes taken from the intake canal of an estuarine power plant and their predicted survival in the discharge canal.

Claridge, P. N. and D. C. Gardner. 1978. Growth and movements of the twaite shad, *Alosa fallax* (Lacepede), in the Severn Estuary. J. Fish Biol., Vol. 12, No. 3, pp. 203-211.

Abstract: Between July 1974 and April 1977, appreciable numbers of O group twaite shad, *A. fallax*, have been collected from the cooling-water intake screens of the Nuclear Power Stations at Oldbury-upon-Severn and Berkeley on the Severn Estuary and at Hinkley Point on the Bristol Channel, England. Young of the year first appeared at Oldbury in July at a size of approximately 32 mm standard length, and grew to approximately 61 mm by October. The downstream migration in the late summer and autumn appeared to be closely correlated with water temperature since movement reached a peak soon after the temperature in the Estuary had declined below 19 degree C, and ceased altogether below 9 degree C. Thereafter, there was virtually no movement of shad until temperatures rose sharply above 7 degree C in the spring. Maturing adult twaite shad were captured in late April and May as they moved into freshwater to spawn, probably in mid-June. Males were recorded slightly earlier during the migration and were generally younger than females. Furthermore, mean lengths and weights for individuals belonging to the different age classes indicated that males were also smaller. Logarithmic relationships between length and weight of young and adult *A.fallax* and for the variation with size in the number of rakers on the first gill arch are presented.

Coastal Zone Consultants. 1979. New England Power Company velocity cap fish entrapment assessment: Phase II-comparative study. Westboro, Mass.: Yankee Atomic Electric Co.

Copeland, B. J. 1975. Report on entrainment and entrainment mortality of zooplankton and larvae, and impingement and movement of fish to Carolina Power and Light Co., Raleigh, N.C.

Coutant, C. C. 1977. Determining the ecological effects of power plant cooling. In: Lectures presented at the Fifth FAO/SIDA Workshop on Aquatic Pollution in Relation to Protection of Living Resources. Scientific and administrative basis for management measures. Manila, Philippines, 17 January-27 February 1977.

Abstract: This review is intended to be an educational article for those who are considering the impacts of power plant cooling for the first time. Unfortunately, there have been few power plant impact studies in tropical waters, so generalizations have been made from the extensive literature from temperate zones. The major environmental impacts from power plant cooling now seem to be recognized. The task now is to quantify the effects, to place theorized effects in the context of local populations and ecosystems at power plant sites, to make reasoned judgements about significance of impacts for both local ecology and man, and to develop mitigating plans for siting, design and operation of new or modified systems that make a reasonable balance between environmental benefit and cost to the consumer of electricity.

DeMartini, E. E. 1983. A Preliminary evaluation of interim monitoring data for coastal, pelagic, and benthic, soft-bottom fishes near San Onofre Nuclear Generating Station (SONGS): a re-evaluation of some SONGS' impingement topics: and completion of exploratory data analyses for pre-operational monitoring data : final report of the University of California, Santa Barbara fish study project for the period: November 1982-October 1983. Santa Barbara, Calif.: Marine Science Institute, University of Califiornia, Santa Barbara.

DeMartini, E. E. 1986. 1986 annual report of the UCSB fish project: preliminary statistical comparisons of baseline and operational samples for otter trawl and lampara seine tasks and estimation and comparison of entrapment and mortality of fishes at SONGS units 1, 2, and 3. Santa Barbara, Calif.: Marine Science Institute, University of California, Santa Barbara.

Dempsey C. H. 1988. Ichthyoplankton Entrainment. Journal of Fish Biology, Vol. 33, pp. 93-102.

Dempsey, C. H. and S. I. Rogers. Ichthyoplankton entrainment at Wylfa power station, Anglesey and implications for a further siting proposal.

Abstract: A 12 month survey of ichthyoplankton in the cooling-water system of Wylfa Power Station and the surrounding 40 km (sup 2) of sea, was carried out between October 1986 and September 1987. The larvae of 31 species and the eggs of 8 species were identified in the survey. Samples taken from the cooling-water system and by boat from offshore were largely similar in respect of species diversity and density. Estimates of annual losses due to entrainment are given both in terms of immediate losses and consequential losses of adults to the population. Estimates of losses of six commercially exploited species are considered in terms of loss to the commercial fishery. Assuming the `worst case' of a 100% mortality of eggs and larvae passing through the cooling system, losses of ichthyoplankton due to entrainment at the existing `magnox' nuclear power station at Wylfa Point are small and could have no significant adverse effect on fish populations of those species entrained. The operation of the proposed `pressurized water reactor' nuclear power station on the same site would increase losses by up to

100%. Such an increase would still not alter the existing situation. No significant adverse effect is likely.

Dew, C. B. 1995. The nonrandom size distribution and size-selective transport of age-0 Atlantic tomcod (*Microgadus tomcod*) in the lower Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 52, No. 11, pp. 2353-2366.

Abstract: From early March until about mid-May 1975 and 1976, the entire Hudson River population of recently hatched Atlantic tomcod, *Microgadus tomcod*, was sorted, by estuarine hydrodynamic forces, into a distinct longitudinal size gradient throughout a 93-km section of the lower estuary. This distribution was evident as a well-ordered progression of mean lengths, beginning upriver with the smallest larvae and increasing in a downriver direction, with the largest larvae being nearer the estuary mouth. Aspects of the passive estuarine transport of larval tomcod during March and April, and the active upriver migrational movement of juveniles greater than 20 mm in length beginning in late April, were deduced from systematic changes in the longitudinal distribution of tomcod mean lengths and associated variances. Abrupt increases in tomcod mean length, variation in length, and population density often occurred just seaward of the 1.0ppt salinity-intrusion boundary. During March-May, vulnerability of tomcod to power-plant entrainment at km 60 - km 69 increased whenever freshwater flow decreased and the 1.0 ppt intrusion boundary moved upriver. The late April - early May appearance each year of age-0 tomcod in impingement samples at km 69 is consistent with the hypothesis of an upriver migration of juvenile tomcod beginning in late April.

Diamond, J. A. 2001. Preliminary study on the impact of entrainment through a heat exchanger at the Holyrood Power Generating Plant on winter marine plankton.

Dimou, N. K. 1990. Numerical simulation of fish larvae entrainment at the Millstone Nuclear Power Station. Publication: [Cambridge, Mass.]: Energy Laboratory, Massachusetts Institute of Technology.

Ecological Analysts, Inc. 1977. Survival of Entrained Ichthyoplankton and Macroinvertebrates at Hudson River Power Plants. Middletown, New York.

Edinger J. E. and V. S. Kolluru. 2000. Power plant intake entrainment analysis. Journal of Energy Engineering ASCE, Vol. 126, No. 1, pp. 1 14.

Abstract: Power plant condenser cooling-water intake entrainment of fish, eggs and larvae is becoming an issue in evaluating environmental impacts around the plants. Methods are required to evaluate intake entrainment on different types of water bodies. Presented in this paper is a derivation of the basic relationships for evaluating entrainment from the standing crop of fish eggs and larvae for different regions of a water body, and evaluating the rate of entrainment from the standing crop. These relationships are coupled with a 3-D hydrodynamic and transport model that provides the currents and flows required to complete the entrainment evaluation. Case examples are presented for a simple river system, and for the more complex Delaware River Estuary with multiple intakes. Example evaluations are made for individual intakes, and for the cumulative impacts of multiple intakes.

Electric Power Research Institute. 1999. Proceedings: 1998 EPRI Clean Water Act Section 316(b) Technical Workshop: Coolfont Conference Center, EPRI, Palo Alto, CA, Report TR-112613, (Apr 1999), 461 pp.

Abstract: Under an October 1995 Consent Decree, EPA is revisiting Clean Water Act Section 316(b) and how it applies to cooling-water intake structures (CWIS). At EPRI's request, EPRI and EPA have established a dialog to share technical information related to Section 316(b) issues. As part of this dialog, EPRI sponsored this technical workshop for EPRI and EPA staff, EPRI's Section 316(b) Technical Advisory Team, and invited guests.

Electric Power Research Institute. 2000. Review of Entrainment Survival Studies: 1970-2000, EPRI, Palo Alto, CA, Report 1000757, (Dec 2000).

Abstract: This report summarizes the results of entrainment survival studies conducted at power stations over the last 30 years. It is the most comprehensive review to date and will be of value to utilities, industries, and government agencies involved in assessing potential environmental impacts of cooling-water intake structures.

Electric Power Research Institute. 2002. Connecticut River Ecological Study Workshop: Revisiting the Impact of a Power Plant: November 15-16, 2001, The University of Connecticut Marine Sciences Institute at Avery Point, EPRI, Palo Alto, CA, Report 1006900 (Apr 2002).

Abstract: The workshop summarized in this CD brought together specialists to review the 1965 to 1973 Connecticut River Ecological Study in the context of current regulatory developments. The earlier effort established the theoretical and scientific basis for power plant ecological impact studies to follow and for environmental impact assessment in general. The study examined the potential impact on the ecology of the lower Connecticut River due to the operation of the Haddam Neck Connecticut Yankee (CY) nuclear powered electric generating station. Results of this study were published in 1976 as the American Fisheries Society Monograph Number One. The study's methodology, results, and conclusions, including information collected during operation and post closure of the CY plant, are of relevance to the ongoing national dialog on the impacts of cooling-water withdrawals on aquatic resources. This dialog is occurring because the U.S. Environmental Protection Agency (EPA) is developing regulations to implement Section 316(b) of the Clean Water Act that are intended to minimize those impacts where they exist. This rule-making effort applies to the regulation of cooling-water intake structures (CWIS) as used by power plant and other industrial operations. The regulations will address the meaning of "adverse environmental impact" (AEI), approaches for assessing the potential for AEI, and measures for minimizing AEI. These measures may include requirements affecting the design, construction, location, and capacity of CWIS that are determined to reflect the "best technology available" (BTA). EPA is collecting information that it will use to develop the regulations. EPRI is providing scientific information to EPA, via both technical reports and technical forums for sharing and discussing scientific data, to support their rule development efforts. This workshop was an EPRI-supported forum for discussion of CWIS technical issues

associated with the now-retired CY plant and the lower Connecticut River.
This workshop provided an opportunity to re-examine the original Connecticut River Study in relation to the long-term operation of CY and in relation to the current ecological condition of the Lower River. All key scientists involved in the Connecticut River Study agreed to participate and re-examine its methods, results, and conclusions. Presentations from scientists and power plant personnel involved in current Connecticut River research supplement the original scientific team. Presentations and discussions provide important insights contributing to the ongoing 316(b) dialog and rule-making effort.
The objective of this workshop was to examine in retrospect the study's methods, results and conclusions. Data gaps that could be resolved through additional field research were identified. Re-visiting the Connecticut River Ecological Study and CY experience provided a unique opportunity and case study to examine key issues relative to the impact of CWIS on aquatic resources.

Elwany, M. H. S., J. Reitzel and M. R. Erdman. 1990. Modification of coastal currents by power plant intake and thermal discharge systems. Coastal Engineering, Vol. 14, No. 4, pp. 359-383.

Abstract: Power plant cooling systems that entrain large volumes of seawater in multiple discharge jets can produce changes in the local field of flow. A case history of observed flow modification is provided by dye studies and records of currents around the diffusers of the San Onofre Nuclear Generating Station (SONGS), which entrain a volume of flow on the order of 1000 m super(3)/s. Field observations of dilutions and velocities in the discharge plume agree well with the results of hydraulic modeling of the diffuser system. Synoptic observations and long-term statistical distributions of current speeds and directions show systematic patterns of altered flow around the diffusers that are more complex than the flow in the model because of interactions with flow modification by local beds of giant kelp.

Environmental Protection Agency. 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316 (b) P. L. 92-500. EPA Office of Water Enforcement, Permit Division, Industrial Permits Branch, Washington D. C., 59 p. Available on-line at http://www.epa.gov/waterscience/316b/

Fletcher, R. I. 1990. Flow dynamics and fish recovery experiments: water intake systems. Transactions of the American Fisheries Society. Vol. 119, No. 3, pp. 393-415.

Gaudy, R. and B. Moatti. 1978. [Study of the mortality of zooplankton transient in the cooling waters of a thermoelectric power plant]. In: Workshop on pollution of the Mediterranean. Antalya, 24-27 November 1978.

Abstract: The mortality of zooplankton sampled from intake and effluent circuits of a power plant (Martigues-Ponteau, Gulf of Fos, France) has been followed during an 18 months study. A vital staining technique was used to determine the proportion of dead and live animals under different conditions of power plant activity. The sampling process, added to the natural mortality caused a mortality rate of 25%. The lethal factors introduced by the cooling-water system were: turbulence (mechanical shock in the

circuits) 21%; thermal shock, whose effect is correlated with the increase of t (about 0 to 12%) and chlorination (31% average). The mortality appeared to affect larger and smaller forms of zooplankton equally. These results are discussed and compared with previous estimations.

Greenwood, M. 2001. Cooling water extraction impacts on lower Forth estuary fish populations. 131st American Fisheries Society Annual Meeting, Phoenix, AZ (USA). 19-23 Aug 2001. (World Meeting Number 000 5724).

Grotbeck, L. M. and J. L. Bechthold. 1975. Fish impingement at Monticello Nuclear-Plant. Journal of the Power Division-ASCE, Vol. 101, Iss. 1, pp 69-83.

Hanson, C. H., J. R. White and H. W. Li. 1977. Entrapment and impingement of fishes by power plant cooling-water intakes: an overview. Mar. Fish. Rev., Vol. 39, No. 10, pp. 7-17.

Abstract: An overview of the recent information available on fish entrapment and impingement by power plant cooling-water intakes is presented. The types of biological problems caused by intake structures, the strengths and weaknesses of various water intake/fish protection systems, and the biological/ecological processes relevant to this problem are discussed. Factors contributing to direct and delayed mortality in screen-impinged fish are examined with emphasis on the relationship between water velocity, impingement time, and physiological stress. In considering the present state of developing impact assessment areas which need refinement, omission, and limitations of present knowledge are pointed out. The biological impact of water withdrawal for power plant cooling can be minimized by consideration of intake sitting and design criteria including site evaluations, cooling system design, and the use of guidance, diversion, and fish salvage systems.

Hartwell, S. I. and R. G. Otto. 1978. Swimming performance of juvenile menhaden (*Brevoortia tyrannus*). Publ. by: JHU/CBI; Baltimore, MD (USA), Dec 1978, 23 p., Spec. Rep. Chesapeake Bay Inst.

Abstract: Critical swimming speeds (CSS) for groups of *B. tyrannus* were determined in an array of time and velocity combinations. CSS varied between 20.7 body lengths (BL/s) at short time intervals (2 min) to 15.8 BL/s at long time intervals (64 min). The experiments were repeated using the same group of fish to assess the effect of previous experience and mean CSS increased by 2.3 BL/s. Tailbeat frequency increased steadily with increasing velocity. Differences in tailbeat frequency between fish in different positions in the groups were noted. This work is part of an investigation to predict fish entrainment at water intakes on the Chesapeake Bay.

Helvey, M. 1985. Behavioral factors influencing fish entrapment at offshore cooling-water intake structures in southern California. Marine Fisheries Review, Vol. 47, No. 1, pp. 18-26.

Abstract: Seven species account for the majority of fish entrapment by offshore cooling-water intake structures in southern California. These fishes include transient species

(queenfish, *Seriphus politus*; white croaker, *Genyonemus lineatus*; walleye surfperch, *Hyperprosopon argenteum*; northern anchovy, *Engraulis mordax* and Pacific pompano, *Peprilus simillimus*), which generally encounter intakes at night, and reef-associated species (shiner perch, *Cymatogaster aggregata* ; and white seaperch, *Phanerodon furcatus*) which utilize intake structures as artificial reefs. The entrapment of these species results from different behavioral activities that bring these species into direct contact with the intake water currents. Future research focused on identifying the mechanisms and different behavioral activities that determine these movements is recommended as the most practical approach for reducing fish entrapment.

Helvey, M. and P. B. Dorn. 1987. Selective Removal of Reef Fish Associated with an Offshore Cooling-Water Intake Structure. Journal of Applied Ecology, Vol. 24, No. 1, (Apr, 1987), pp. 1-12.

Abstract: (1) Fish captured, tagged and released at an offshore intake structure, together with a comparison of field population densities and respective impingement rates, indicated intake removal to be a selective process. Intake-associated species comprised a small proportion of the total number of fish removed and were not removed in numbers proportional to their field densities. (2) The rheotropic behavior of four species associated with the intake structure demonstrated that, given adequate water clarity, they avoided being trapped by intake water currents. (3) Diurnally active species seeking benthic cover at night were least susceptible to intake removal. Diurnally active species that hover in the water column at night and predators that periodically feed at twilight and evening hours were more susceptible to removal. Nocturnal fish were most susceptible to removal.

Helvey, M. and R. W. Smith. 1985. Influence of habitat structure on the fish assemblages associated with two cooling-water intake structures in southern California. Bulletin of Marine Science, Vol. 37, No. 1, pp. 189-199.

Henderson, P. A., A. W. H. Turnpenny and R. N. Bamber. 1984. Long-term stability of a sand smelt (*Atherina presbyter* Cuvier) population subject to power station cropping. Journal of Applied Ecology, Vol. 21, No. 1, pp. 1-10.

Abstract: The sand smelt (*A. presbyter* Cuvier) is a species of fish particularly susceptible to impingement at power station cooling-water intakes. Data are available from 1971 to 1981 for the numbers and sizes of sand smelt impinged at Fawley Power Station, Hampshire, during which time it was the commonest impinged fish species. Recruitment into the population of a new 0 group is in July/August. Somatic growth only occurs during the summer and autumn. There is a seasonal inshore migration for spawning by 2 year and older fish, and virtually none survive after 3 years. The observed population age structure did not change significantly over the period of this study, despite age-selective cropping by the power station. It is suggested that this stability is afforded by a density-dependent response. It is concluded that the 10 years of operation of Fawley Power Station has had no significant effect on the long-term stability of the local sand smelt population.

Hicks, D. B. and L. Tebo. 1985. Power plants: Their present and future impact on the aquatic resources of Tampa Bay. Proceedings. Tampa Bay Area Scientific Information Symposium, Rep. Fla. Sea Grant Program., No. 65, p. 525

Abstract: Presently, 5 steam electric plants are using Tampa Bay as a source of condenser cooling water and as a site for disposal of waste heat. The subject of this presentation is the environmental data and assessment strategies used to evaluate impacts of these facilities on the aquatic resources of Tampa Bay. The areal extent of thermal impacts can be estimated and regional consequences assessed. Siting criteria are discussed as the most effective means of minimizing future environmental impacts. Existing technologies are reviewed as "fixes" for currently operating facilities.

Holmes, R. H. A. and P. A. Henderson. 1990. High fish recruitment in the Severn Estuary: The effect of a warm year? Journal of Fish Biology, Vol. 36, No. 6, pp. 961-963.

Abstract: In 1989, exceptionally strong recruitment has been observed in several fish species in the Bristol Channel. This is thought to be a consequence of the unusually high sea temperatures during the 1988-89 winter and the following spring and summer. The Marine Biological Unit of National Power (currently a division of the C.E.G.B.) has been monitoring catches of marine fishes and invertebrates on the cooling-water screens of Hinkley Point `B' Power Station on the south side of the estuary of the River Severn at regular monthly intervals since January 1981. Animals, seaweed and debris are normally washed off into hoppers and then sluiced into collecting baskets for disposal. Samples were collected in plastic baskets of 6-mm mesh placed under the spouts of the hoppers or where the water enters the collecting baskets. The sampling dates were chosen to lie between spring and neap tides. The number of animals collected by two screens for 6 h from high water to low water was recorded. Sea water temperatures for each date are shown in Fig. 1(a). Average temperature rose from 1981 to 1983 and, after falling to a trough in 1985, rose steadily to the warm summer of 1989. Unusually high numbers of five fish species [bass, *Dicentrarchus labrax* (L.); twaite shad, *Alosa fallax* Lacepede; red mullet, *Mullus surmuletus* L.; herring, *Clupea harengus* L.; pout *Trisopterus luscus* (L.)] and of the invertebrate swimming crab *Liocarcinus holsatus* (Fabricius) were observed in 1989. For bass, the relationship between successful recruitment and temperature is well established; authors record good recruitment in 1976. 1979 and 1982-83, corresponding to warm sea temperatures in the same years. Peaks of 0-group bass were also observed at Hinkley during the winter of 1981-82 and autumn of 1983. The September and October 1989 samples produced the highest captures for the decade. Twenty twaite shad were caught at Hinkley in March 1985, since when few were observed until September 1989 when 39 were caught. Aprahamian states that peak immigration by adult twaite shad into the Severn Estuary occurs at temperatures of between 10.6 and 12.3 degree C, while Claridge & Gardner attribute a low observed number of shad at Oldbury-on-Severn in 1974 (compared with 1975 and 1976) to the relatively cold spring and summer temperatures of that year; they found that shad started to move out of the estuary when temperatures fell to 19 degree C. Red mullet are relatively rare at Hinkley, but nine were found in the August sample of 1983 when the sea temperature was 22 degree C, after which few were seen until 26 occurred in September 1989. The herring occurred in brief peaks of 14 and 47 in 1982 and 1987; unusually 36 were captured in October 1989.

Horwitz, R. J. 1987. Assessment of power plant impact. Impingement studies. Lecture Notes on Coastal and Estuarine Studies. Vol. 23, pp. 254-269.

Hoss, D. E. and J. H. S. Blaxter. 1981. Effects of Rapid Changes in Hydrostatic Pressure on the Larvae of Atlantic Herring (*Clupea harengus* L.). The Early Life History of Fish: Recent Studies, Rapp. P.-V. Reun. Ciem., Vol. 178, pp. 328-329.

Abstract: Fish with gas-filled organs are most likely to be at risk when subjected to the pressure changes, which occur during passage through the cooling-water system of a thermal power station. Larval herring from 11-39 mm T.L. were subjected to different series of pressure changes intended to simulate passage through the cooling-water system of a power station. Results showed that the effects of large rapid pressure changes on herring larvae were minimal until the bulla developed. As expected the larvae seemed to go through a particularly vulnerable stage at the length range 25-30 mm when the adaptation mechanism to changes in hydrostatic pressure is missing. With respect to power stations, only herring below about 40 mm T.L., which can penetrate the intake screens, will be at risk and then only from pressure increases which may cause implosion of the bulla membrane before the adaptation mechanism has developed. Herring cannot secrete gas into the bulla or swim bladder so there is never likely to be excess gas to cause harm to the bulla membrane on pressure decreases. Both pressure increases and decreases may be harmful by causing hyperactivity.

Huh, H. T. 1980. Effects of Thermal Effluents on Marine Biota in Coastal Waters of Korea. Acta Oceanogr. Taiwanica., No. 11, pp. 1-9.

Abstract: To evaluate the effects of thermal effluents from the power plants on marine biota, marine ecological studies have been conducted in the vecinities of Kori Nuclear Power Plant, located near the tip of south-east coast of Korea. The results have shown a possibility of damage, though not conclusive yet, to coastal environment and fisheries by the thermal discharges. Densities of plankton populations at the discharge water were much lower than those of the intake which may reflect possible metabolic impairment and/or physical breakdown of the planktons by the thermal and mechanical stresses in the cooling systems. The number of larval fish going into the cooling system of Kori Plant, Unit 1, during the reproductive months (May-July), was estimated to be 1-502 per second in every 40-ton of cooling water used. The mortalities of planktons due to operation of the power plant appear to have minor effect on the plankton populations in surrounding waters, but the resulting effects of larval fish mortality due to the entrainment are yet to be determined.

Huish, M. T. and J. Geaghan. 1987. Movements and impingements of juvenile spot. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies. 1987 October 4-7; Vol. 41, pp. 15-23.

Hung, T-C., C-C. Huang and K-T. Shao. 1998. Ecological survey of coastal water adjacent to nuclear power plants in Taiwan. Chemistry and Ecology, Vol. 15, pp. 129-142.

Abstract: A total of six nuclear reactors installed in three power plants, two along the northern and one along the southern coasts of Taiwan, started their operations one after

another since October 1977. Owing to the large quantities of cooling-water intake into and discharge from the plants, some environmental factors such as water temperature, chlorine, environmental radioactivity and near shore currents may be significantly changed. Variations of these abiotic environmental factors may influence the biological activities in the ecosystem, particularly doing some kinds of damage to marine biological resources. Therefore, the possible environmental impact upon the biological systems including the fishery resources along the northern and southern coasts of Taiwan should be studied before and during the plant operation. We have started the long-term programmes of biological, chemical and hydrographical surveys of the nuclear power plant sites on both northern (since July 1974) and southern (since July 1979) coasts of Taiwan. The survey items include ocean currents, physical and chemical properties of sea water, primary productivity specific compositions and interspecific relationships among phyto- and zooplankton, algae, invertebrates, corals, and fishes; and radionuclides in water and biological specimens, and fishery statistics. In general, except for a few events, the operations of the six units of nuclear power plants have not produced detectable effects on the marine ecosystem. Radioactivity levels and radionuclides in water and the biological specimens remained the same as background levels throughout the survey period. However, the events of coral bleaching and fish body anomalies caused by thermal discharges were observed respectively along the outlets of third and second Nuclear Power Plants. The purposes of this paper are to report and evaluate these two events during the operations of nuclear power plants in Taiwan.

Jan, R-Q, J-P Chen, C-Y Lin and K-T Shao. 2001. Long-term monitoring of the coral reef fish communities around a nuclear power plant. Aquatic Ecology, Vol. 35, no. 2, (Jun 2001), pp. 233-243.

Abstract: Over the past 21 years (1979-1999) we have observed temporal changes in the fish communities on a coral reef around a nuclear power plant in southern Taiwan. Data used for analyses were collected bimonthly by scuba-diving ichthyologists at four sub-tidal stations (Stations A, B, D, E). The commercial operation of the nuclear power plant was launched in the summer of 1984. During the study period the number of fish species varies, with the coefficient of variation (CV) ranging from 19.0% (Station A) to 25.2% (Station D). Nevertheless, the sequential data on number of species follow a random trend in terms of runs up and down at all four stations. This characteristic persists both before and after the initiation of power plant operation. Dendrograms drawn using UPGMA (un-weighted pair-group method using arithmetic averages) on the dissimilarity coefficients between yearly fish occurrences show that the years 1980-1984 are more closely grouped than any other years. This phenomenon prevails at all stations, indicating that wide-scale change occurred between 1984 and 1985. After the power plant began operation, changes in water temperature were minute at these sub-tidal stations. Impacts from other sources such as chlorine release and fish impingement seem remote. We believe temporal variations in the studied fish communities can be better explained as arising from natural fluctuations of environmental factors as well as physical disturbance caused by typhoons. The latter factor is also thought to account for the major faunal change between 1984 and 1985.

Jeffries, P., S. Hale and A. Keller. 1986. Finfish compilations for Mt. Hope Bay and the Providence River, Rhode Island: otter trawls and power plant intake screens. Kingston, R.I.: Graduate School of Oceanography, University of Rhode Island, (Dec. 1986).

Jeng, C-H., K-T. Lee and C-H. Liao. 1992. The use of stationary hydroacoustic transducer to study dial and seasonal influences on the distribution of fish school in water adjacent to the cooling water intake of Nuclear Power Plant III. Journal of the Fisheries Society of Taiwan. Vol. 19, No. 4, pp. 289-298.

Jennings, S. 1992. Potential Effects of Estuarine Development on the Success of Management Strategies for the British Bass Fishery. Ambio, Vol. 21, Iss. 7, pp. 468-470.

Jensen, A. L. and T. A. Hamilton. 1982. Application of a conventional fishery model for assessment of entrainment and impingement impact. Environmental Biology of Fishes. Vol. 7, No. 2, pp. 181-185.

Johnson, D. R. 1983. Effects of rainfall, recruitment, and the operation of the Cedar Bayou Electric Generating Station (Baytown, Texas) on the dynamics of fish and macrocrustacean communities in the brackish intake and discharge waters. Dissertation Abstracts International, B: Sciences and Engineering. Vol. 43, No. 11.

Johnson, K. W. and K. Strawn. 1973. Occurrence and abundance of fishes in the intake and discharge areas of the Cedar Bayou Power Station before and during the first year of plant operation. Houston, Tex.: Houston Lighting & Power Company.

Karaas, P. 1992. Zooplankton entrainment at Swedish nuclear power plants. Marine Pollution Bulletin, Vol. 24, No. 1, pp. 27-32.

Abstract: Studies on zooplankton entrainment with the cooling-water at four Swedish nuclear power plants demonstrated that mortality of crustaceans caused by mechanical damage and temperature elevation was low. Chlorination against fouling organisms, however, occasionally caused raised mortality. The greatest effect found on the zooplankton communities was caused by filter feeders attached to the walls of the cooling-water systems. Up to about 50% of the plankton was filtered off, and the effect was positively related to the lengths of the cooling-water tunnels. Delayed mortality was low in most taxonomical groups except in the cladocerans. As the volumes of water passing through the cooling-water systems are very large, the effect on the zooplankton community was considered as severe. At one of the plants the estimated yearly average loss of crustacean zooplankton was some hundred tons.

Khalanski, M., O. Mikolacek and F. Travade. 1981. (Fish catches at power plants pumping stations. Quantitative estimation of *in situ* catches at the Dunkerque power plant and experimental study of devices for diverting fish at the Gruissan Station (Aude) (France).). (Influence of Thermal Discharges on Marine and Estuarine Organisms.), pp. 777-799.

Abstract: Impingement of fish has been observed on the rotating filters of Dunkerque thermal power plant. The impinged fish were caught and 31 species were identified and examined (length-weight, health, survival rate). The number of fish that die after

impingement has been estimated per year. An experimental device to divert fishes from the power plant intake station, with deflecting screens orienting fishes in a bypass, has been tested.

Koehler, A. 1981. Fluctuations of the ichthyo-fauna in the Elbe estuary: An indicator for a disturbed ecosystem. Helgolander Meeresuntersuchungen. Hamburg, Vol. 34, No. 3, pp. 263-285.

Abstract: During 1978, 22 fish species (particular *Anguilla anguilla* L., *Platichthys flesus* L., *Osmerus eperlanus* L., *Gasterosteus aculeatus* L., *Lampetra fluviatilis* L., *Alosa fallax* (Lacepede), G*ymnocephalus cernua* L., *Clupea harengus* L. and *Sprattus sprattus* L.), sampled at the intake of the cooling system in the nuclear power plant at Brunbuettel (Elbe estuary) were analyzed for quantities and size distribution. Spawning times and seasonal migrations of the fish species investigated corresponded to appropriate temperatures of the Elbe water. The diversity of fish species from the cooling water proved to be representative for the ichthyo-fauna of this particular estuarine area. At least 190 tons of fish per year, were estimated to be annihilated by the suction of cooling water into the nuclear power plant. In spite of the progressive development of regional industries and the increasing discharges of cooling water, temperature in the estuary has remained largely unaffected up till now. The oxygen content of the heavily polluted lower Elbe river, however, has become mainly dependent on the amount of fresh water flowing from the upper Elbe river. Varying oxygen concentrations downstream of Hamburg and at Brunsbuettel are considered to be responsible for migrations of certain fish species (mainly flounder and smelt) between the Brunsbuettel region and their habitats further upstream which were occupied before the process of industrialization initiated.

Langford, T. E., N. J. Utting and R. H. A. Holmes. 1977. Factors affecting the impingement of fishes on power station cooling-water intake screens. European Marine Biology Symposium, No. 12, pp. 281-288.

Littrell, J. A. and J. V. Biaggi. 1979. Petroleum refinery impacts on near shore marine environment. Proceedings Association of Island Marine Laboratories of the Caribbean. Mayaguez, Vol. 14, p. 29.

Abstract: A one year biological monitoring program was conducted in Tallaboa and Guayanilla Bays, Puerto Rico to assess the impacts of petroleum refinery facility operations on the near shore marine life of Tallaboa and Guayanilla Bays. Topics covered are: 1) impacts from impingement of nektonic organisms on cooling-water intake screens; 2) Quantity of zooplankton available for entrainment in cooling-water system; 3) assessment of near shore fish populations; 4) sampling of fouling and interstitial organisms; 5) water quality of Tallaboa and Guayanilla Bays; and 6) toxicity testing of heated effluent water. Results of the monitoring program are discussed.

Love, M. S., J. Caselle and L. Snook. 1999. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara Channel and Santa Maria Basin. Bulletin of Marine Science, Vol. 65, No. 2, pp.497-513, (Sep 1999).

Abstract: Mussel shell mounds surround all offshore oil and gas platforms in California. These biotic reefs are formed when large clumps of mussels are dislodged from the superstructure. In 1997, we surveyed the fish assemblages on the mussel mounds surrounding seven platforms in the Santa Barbara Channel and in the Santa Maria Basin, California. The objectives of this study were (1) to document the fish assemblages on the mussel reefs, (2) to investigate the spatial patterns of use of parts of mussel reefs by various fish species and (3) to compare species assemblages, population densities and fish sizes on the mussel reefs with those on adjacent platform bottoms. We observed at least 35 species on the mussel mounds, 18 of which were rockfishes (genus *Sebastes*). Most of the species that were found both in large numbers and were encountered at a number of mussel mounds were solitary, benthic forms. Most species appeared to be non-randomly distributed among parts of the mussel mounds with different percent shell cover. All species combined and all rockfish species tended to be slightly but significantly over-represented on areas of 80-100% cover (all species: chi super (2) = 227, n = 5, P < 0.001, all rockfishes: chi super (2) = 211, n = 5, P < 0.001). Species richness, density (fish100 m super (-2)) and mean lengths of fishes were all less on the mussel mounds than on the platform bottoms. However, cluster analysis revealed that the species composition on each mussel mound is more similar to its adjacent platform bottom than to other mounds. There did not appear to be a distinct "mussel mound community", instead the mussel mounds should be considered as an integral part of the oil platform system.

Love, M. S., J. E. Caselle and K. Herbinson. 1998. Declines in near-shore rockfish recruitment and populations in the southern California Bight as measured by impingement rates in coastal electrical power generating stations. Fishery Bulletin, Vol. 96, No. 3, (Jul. 1998), pp. 492-501.

Abstract: We used data from fish impingement studies of the coastal electric generating stations of Southern California Edison Company to examine patterns of near-shore rockfish abundance in the southern California Bight. The impingement data spanned 17 years (1977-93), comprised a minimum of several surveys per month and included power plants from throughout much of the Bight. Sixteen rockfish species were taken and six (olive rockfish, *Sebastes serranoides*; brown rockfish, *S. auriculatus*; bocaccio, *S. paucispinis*; blue rockfish, *S. mystinus*; treefish, *S. serriceps*; and grass rockfish, *S. rastrelliger*) accounted for 99% of all rockfish caught. Most of these fishes were between 0 and 2 years old. Catch rates for all six of these species have dropped substantially since the inception of the survey in 1977. Catch rates peaked in the early 1980s, dropped by a factor of over 100 to a low in 1984, and have generally remained low through 1993. One species, blue rockfish, has not been taken since 1984. We compared our rockfish impingement data from one power station in King Harbor, Redondo Beach, with data from scuba transects conducted during the same period within King Harbor. The results of the two surveys strongly suggest that the catch rates of rockfishes by power plants reflect the abundance of these fishes surrounding the plants. We suggest that the reduction in the abundance of near-shore rockfishes in the southern California Bight is due to both decreased recruitment success, reflecting long-term adverse oceanographic conditions, and to over-fishing.

Maes, J., A. Taillieu, P. A. Van Damme, K. Cottenie and F. Ollevier. 1998. Seasonal patterns in the fish and crustacean community of a turbid temperate estuary (Zeeschelde Estuary, Belgium). Estuarine, Coastal and Shelf Science, Vol. 47, No. 2, (Aug 1998), pp. 143-151.

Abstract: Fish and crustaceans were sampled for 1 year in the upper reaches of a temperate estuary characterized by high turbidity and a tidal range of up to 5 m. Samples were taken in the cooling-water circuit of the Doel Nuclear Power station (Zeeschelde, Belgium). Between July 1994 and June 1995, 55 fish species, two shrimp species and four crab species were recorded. The fish community was composed of 36 marine species, 16 freshwater species and three diadromous species. Shrimps, Gobiidae and Clupeidae dominated the samples both in numbers and biomass. An exceptionally clear seasonal succession was observed in the species composition. It is argued that young fish and crustaceans use the highly turbid Zeeschelde Estuary as a refuge from predators.

Maes, J., J. Pas, A. Taillieu, P. A. Van Damme and F. Ollevier. 2001. Sampling of fish and crustaceans at the cooling water intake of an estuarine power plant: A comparison with stow net fishery. Archive of Fishery and Marine Research, Vol. 49, Iss. 1, pp 27-36.

Abstract: Fish and crustaceans were sampled in November 1995 in the cooling-water intake of the nuclear power plant Doel (Zeeschelde Estuary, Belgium) and by stow nets, to determine possible differences in species abundance, species biomass, and mean species length between the two methods. A total of 39 species were caught, 32 by stow net and 33 at the intake, with 26 species being caught by both methods. The abundance and biomass were several times higher at the intake than in the stow net samples. Although the average length was higher in the stow net samples in the case of most species, almost all length classes of each population were also present in the samples from the cooling-water intake. The results suggest that the cooling-water intake is an effective means to collect fish and crustaceans, and reflects the species abundance in the surrounding waters, if the method is combined with surveys to separate local events from long-term trends.

Maes, J., P. A. Van Damme, A. Taillieu and F. Ollevier. 1998. Fish communities along an oxygen-poor salinity gradient (Zeeschelde Estuary, Belgium). Journal of Fish Biology, Vol. 52, No. 3, (Feb 1998), pp. 534-546.

Abstract: Fish living in the tidal fresh and brackish water reaches of the Zeeschelde Estuary were studied in samples collected from the cooling-water inlets of three power stations. Between July 1994 and June 1995, 42 different species were recorded including 26 marine migrants, 14 freshwater species and two diadromous species. Species number as well as fish abundance were correlated significantly with salinity and oxygen concentration. The community structure was analyzed with a correlation biplot based on principal component analysis of the root-root transformed fish abundance. Four separated communities could be distinguished since the first principal component expressed a salinity and the second a temperature gradient. During summer and fall *Pomatoschistus microps*, *P. minutus*, *P. lozanoi* and *Syngnathus rostellatus* were most abundant in the brackish-water reach. At this time, freshwater species seemed to avoid

the freshwater area. During winter, *Sprattus sprattus*, *Clupea harengus* and *Dicentrarchus labrax* were the dominant species of the brackish-water zone while the freshwater reaches were dominated by *Gasterosteus aculeatus*. Migrating fish such as *Pleuronectes flesus*, *Lampetra fluviatilis*, *Anguilla anguilla* and *Osmerus eperlanus* were restricted to the brackish environment.

Maitland, P. S., K. East and K. H. Morris. 1980. Fish entrained in 1977 at Cockenzie Power Station, in the Firth of Forth. Forth naturalist and historian. Stirling, Vol. 5, No. 1980, pp. 35-45.

Abstract: Power station intakes are of value in monitoring water quality or studying population dynamics of various species. A pilot project was set up in 1977 to monitor the Cockenzie Power Station, Firth of Forth. This power station is situated on the open seaward end of the estuary, where tidal and salinity conditions are marine. A total of 28 different species of fish were recorded, but the total catch was dominated by relatively few species, notably sprat, herring, whiting and sand goby. The species recorded were: *Sprattus sprattus, Clupea harengus, Anguilla anguilla, Syngnthus acus, Entelurus aequoreus, Merlangius merlangus, Pollachius virens, Gadus morhua, Raniceps raninus, Ciliata mustela, Ammodytes tobianus, Hyperoplus lanceolatus, Trachinus vipera, Pomatoschistus pictus, Pomatoschistus minutus, Pholis gunnellus, Zoarces viviparus, Crenimugil labrosus, Myoxocephalus scoripius, Taurulus bubalis, Agononus cataphractus, Cyclopterus lumpus, Liparis liparis, Liparis montagui, Spinachia spinachia, Limanda limanda, Platichthys flesus,* and *Pleuronectes platessa* .

Marcy, B. C., Jr. 1975. Entrainment of organisms at power plants, with emphasis on fishes. Fisheries and energy production: A symposium.

Abstract: An overview of the recent information available on entrainment, specifically on fish eggs and larvae, is presented. The components of inner-plant mortality (thermal, mechanical and biocidal effects) are discussed, with emphasis on recent data on mechanical damage. Sampling considerations for entrainment studies as well as philosophies and suggestions for reducing entrainment losses are presented. Power plant impact can be minimized by siting in non-productive areas and going to closed cooling systems, i.e., lower intake volumes, since the mortality of meroplankton is directly related to the volume entering the intake. The low volume concept is presently the only effective approach to minimizing the adverse effects on entrained organisms. If studies continue to reveal high percentages of mechanical damage relative to thermal or chemical effects, future alternative strategies may also include the raising of condenser {delta} T's while lowering the intake water volume, i.e., decreasing the number of entrained organisms vulnerable to mortality.

Marcy, B. C., Jr. 1976. Planktonic fish eggs and larvae of the lower Connecticut River and the effects of the Connecticut Yankee Plant including entrainment. American Fisheries Society Monograph. Vol. 1976, No. 1, pp. 115-139.

Mathur, D., P. G. Heisey and N. C. Magnusson. 1977. Impingement of fishes at Peach Bottom atomic power station, Pennsylvania. Transactions of the American Fisheries Society, Vol. 106, No. 3, pp. 258-267.

McBride, R. S. and K. W. Able. 1994. Reproductive seasonality, distribution, and abundance of *Prionotuscarolinus* and *P. evolans* (Pisces: Triglidae) in the New York Bight. Estuarine, Coastal and Shelf Science, Vol. 38, No. 2, pp. 173-188.

Abstract: The reproductive seasonality, distribution, and abundance of two sympatric searobins, *Prionotus carolinus* (Linnaeus) and *P. evolans* (Linnaeus), were investigated using multiple gears (plankton nets, seines, trawls, and powe rplant impingement samples) in several New Jersey estuaries and across the continental shelf of the New York Bight. Reproduction occurred from May to October and peaked in July or August based on collections of eggs (*Prionotus spp*.) near Little Egg Inlet, during 1972-75. The larvae were present July-October and abundance peaked in September. Eggs and larvae were more abundant at inner continental shelf stations compared to estuarine stations. Juvenile (<100 mm standard length) *P. carolinus* were primarily found at inner shelf habitats from September to December, but they were also collected in much colder months (i.e. February-June). Juvenile *P. evolans* were captured in both estuarine and inner shelf habitats from July to December. *Prionotus carolinus* was generally more numerous and more frequently collected in trawls compared to *P. evolans*, but diel period, season, and habitat all affected measured abundance. Catches for both species were higher and more frequent at night. Both species were collected from May to November, but *P. carolinus* arrived earlier to (and emigrated sooner from) coastal habitats than *P. evolans*. Each species was also distributed differentially between estuarine and continental shelf habitats, although they frequently occurred together. A canonical discrimination analysis showed that *P. evolans* was found in seasonally warmer, less oxygenated, and more turbid habitats than *P.carolinus*. In addition, *P. carolinus* was found scattered near the edge of the continental shelf during winter (i.e. January-March) when *P. evolans* was not collected in the New York Bight. Temperature, in particular, helps explain the observed inter specific differences in seasonal distribution at a small scale (i.e. in the estuary) as well as at a large scale (i.e. across the continental shelf).

McDonough, T. A. and P. A. Hackney. 1979. Relationship of threadfin shad density and size structure to impingement at a steam-electric plant. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies. Vol. 33, pp.639-647.

McDonough, T. A. and P. A. Hackney. 1979. Relationship of threadfin shad density and size structure to impingement at a steam-electric plant. Proc., Annu. Conf., Southeast. Assoc. Fish Wildl. Agencies, Vol. 33, 639-647.

Abstract: Threadfin shad (Dorosoma *petenense*) impingement at the Cumberland Steam-Electric Plant followed a seasonal pattern related to the abundance and length distribution of young-of-year fish. Electrofishing samples taken near the plant showed a similar pattern. The number of impinged fish (larger than 50 mm) decreased rapidly with increasing length due to reduction in abundance by natural mortality. Impingement mortality was found to be length dependent. Most individuals, less than 50 mm in length passed through the screens, while increasingly larger individuals were more likely to become impinged. Impinged fish less than 100 mm total length tended to be more plump

than fish collected in rotenone samples, while impinged fish larger than 100 mm tended to be in poorer condition.

Mclean, R. B., J. J. Beauchamp, V. E. Kane and P. T. Singley. 1982. Impingement of threadfin shad: effects of temperature and hydrography. Environmental Management. Vol. 6, No. 5, pp. 431-439.

McLean, R. I. 2002. Maryland power plant cooling water intake regulations and their application in evaluation of adverse environmental impacts. [Annapolis, MD]: Maryland Power Plant Program, Dept. of Natural Resources.

Merriner, J. V. and A. D. Estes. 1976. Ecological study of the tidal segment of the James River encompassing Hog Point: 1975 final technical report : appendices to section 3 A, plant entrainment of ichthyoplankton at the VEPCO nuclear power station. Gloucester Point, Va.: Virginia Institute of Marine Science.

Milliken, D. M., R. C. Baird and A. Feinstein. 1973. A review and annotated bibliography of the problem of fish entrapment at power generating facilities. St. Petersburg, Fla., University of Florida, Marine Science Inst.

Moazzam, M. and S. H. N. Rizvi. 1980. Fish entrapment in the seawater intake of a power plant at Karachi coast. Environ. Biol. Fish, Vol. 5, No. 1, pp. 49-57.

Abstract: The study deals with the entrapment of fishes in the intake of Karachi Nuclear Power Plant. A total of 62 species of marine fishes belonging to 43genera were observed entrapped in the seawater intake. *Therapon puta*, *Liza waigiensis, Abudefduf septemfasciatus*, and *Lagoceptalus inermis* were the most common. Mass mortalities of the juveniles of *Sardinella sindensis* were recorded in September and October of 1974, 1975, and 1977. Commercially important fishes such as sardines, mullets and anchovies, were entrapped in the intake of the power plant in considerable numbers at various times of the year. The majority of fishes removed from the screen washes of the power plants were killed by impingement.

Moorehead, P. W. and M. Service. 1992. Capture of fish on screens of power stations in Northern Ireland. Irish Naturalists' Journal (Belfast), Vol. 24, No. 1, pp. 3-8.

Murdoch, W. W., R. C. Fay, B. J. Mechalas and others. 1989. Final report of the Marine Review Committee to the California Coastal Commission. [San Francisco, CA]: Marine Review Committee.

Nair, K. V. K. 1994. Condenser cooling using seawater: Problems and prospects. Training Programme in Modeling and Monitoring of Coastal Marine Pollution (Mamcomp), November 21-December 16, 1994. Lecture Notes. Indian Inst. Of Technol., New Delhi (India), pp. 129-137.

Abstract: Electric Power Plants are often strategically located in close proximity of water bodies such as lakes, rivers, estuaries and coastal waters, so as to make use of them as heat sinks. In addition to waste heat, these power plants also release chlorine trace metals, fly ash, and low level radioactive wastes (if the source of energy is nuclear) into

the aquatic environment. Further, in the cooling circuit aquatic organisms are subjected to effects of entrainment and impingement. This paper attempts to state the major environmental and operational issues involved, in an integrated manner, with a view to involve a comprehensive survey strategy for the study of aquatic ecosystems used for industrial cooling. An attempt is also made to draw lessons from the experience at Kalpakkam, where studies on operational and ecological problems around a power plant have been in progress for the last several years.

Nisbet, R. M, W. W. Murdoch and A. Stewart Oaten. 1996. Consequences for adult fish stocks of human induced mortality on immatures. In: Schmitt, R. J. and C. W. Osenberg, [Eds]. Detecting ecological impacts: concepts and applications in coastal habitats. Academic Press. San Diego, New York. pp. 257-277.

Nitschke, P., M. Mather and F. Juanes. 2002. Evidence for density-dependent mortality in recruitment of a temperate reef fish, cunner *Tautogolabrus adspersus*, among similar reefs in the vicinity of an anthropogenic disturbance. Marine Ecology Progress Series, Vol. 226, (Jan. 2002), pp. 165-178.

Abstract: Determining the factors that regulate recruitment of cunner *Tautogolabrus adspersus*, a temperate reef fish, can help assess the effect of an anthropogenic disturbance on population abundance. The relative abundance of cunner recruits was tracked over 1 reproductive season via visual counts on line transects across similar habitats at 4 sites across 3 boulder reefs in the vicinity of the Pilgrim Nuclear Power Station (PNPS) in Plymouth, Massachusetts, USA. Habitat characteristics including macroalgae structure, canopy height, rugosity (a measure of structure complexity), temperature, and visibility were measured at each site to assess the influence of these factors on recruit abundance. We assumed that immigration and emigration were not responsible for recruit abundance patterns through time due to the sedentary life history of cunner recruits. We observed differences in recruit abundance over the settlement period among reefs, which were likely the result of differences in settlement. However recruitment at the end of the post-settlement period was similar across reefs. Recruit mortality rates among reefs differed in the post-settlement period, with the reef that had the highest density also having the highest mortality rate. Post-settlement mortality rates provided evidence for density-dependent mortality, since habitat and abiotic factors failed to explain the difference in mortality among reefs. Consequently, because of the existence of density-dependent processes in the post-settlement stages, entrainment mortality of the pre-settlement egg and larval stages by the PNPS will have a diminished effect on the local cunner population. An additional assessment of within-reef variability in recruitment also suggests recruitment success is sensitive to small changes in habitat structure which can occur over the recruitment season.

Normandeau Associates. 1975. The impact of entrainment by the Seabrook Station. Bedford, N.H.: The Associates.

Olson, M. M. 1987. Assessment of power plant impact. Entrainment studies. Zooplankton entrainment. Lecture Notes on Coastal and Estuarine Studies. Vol. 23, pp. 240-250.

Pawson, M. G. and D. R. Eaton. 1999. The influence of a power station on the survival of juvenile sea bass in an estuarine nursery area. Journal of Fish Biology, Vol. 54, no. 6, (Jun. 1999), pp. 1143-1160.

Abstract: (1) Trawl surveys in the estuary of the River Medway in the autumns of 1987-1991 have shown that the distribution of juvenile sea bass *Dicentrarchus labrax* is strongly associated with the warm-water outflow from Kingsnorth power station. (2) In years of low abundance of first-year bass, very few were caught outside the warm-water discharge channel, whereas proportionately more fish of abundant year classes occupied the main river. (4) About 15% of the available juvenile bass population died on the cooling-water intake screens at Kingsworth in the autumn and winter of 1987 and 1988. (5) However, growth and survival of first-year bass in the Medway Estuary may be enhanced by the power station's warm-water effluent, such that over-winter mortality due to inadequate nutritional reserves and low temperatures may be considerably reduced.

Piet, G. 1998. Impact of environmental perturbation on a tropical fish community. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 55 (August. 1998), pp. 1842-1853.

Polgar, T. T., M. A. Turner and J. K. Summers. 1988. The effect of power plant entrainment on the population dynamics of the bay anchovy (*Anchoa mitchilli*). Ecological Modelling. Vol. 41, No. 3 4, pp. 201-218.

Quinby-Hunt, M. S., P. Wilde and C. W. Case. 1984. Environmental considerations: Ocean thermal energy conversion (OTEC) on Pacific Islands. Proceedings Of The Pacific Congress On Marine Technology, Honolulu, Hawaii, April 24-27. 1984, pp. 53-58.

Abstract: Ocean Thermal Energy Conversion (OTEC) has been proposed as an alternative energy source for tropical and sub-tropical Pacific islands. It is a relatively benign technology, however a number of environmental issues must be addressed. These include the effects of: biota attraction, organism impingement/entrainment, biocide impacts on non-target organisms, redistribution of oceanic properties, and release of trace constituents. Safety and plant survivability must be assured. Mitigation strategies can and should be devised prior to final site and design selection. Once the site and design are selected, a site- and design-specific review of potentially significant environmental concerns should occur.

Reay, P. J. and M. B. Culley. 1980. Fish and fisheries in the Solent. In: The Solent estuarine system. An assessment of present knowledge. Publ. by: Nat. Environ. Res. Counc. Publs., Swindon (UK)., (Nov. 1980), Ser. C, No. 11 pp. 86-91.

Abstract: There are three types of fisheries in the Solent region: commercial; sport and anadromous sport fisheries. Statistics are not accurate, however, catch by rod and line equals commercial fishing operations. The area is more important for sea angling than for commercial fisheries. Counts and/or weights of fish collected on the cooling-water intake screens of the power station at Fawley have been taken since 1973. A total of 73 spp have been recorded. The most abundant are sand smelt, sprat, pouting, bass, great pipefish, sand goby, herring, golden mullet, flounder and whiting. There has also been a survey of fish in Langstone Harbour and a MAFF survey of young fish in the Solent

region. A table gives a check list of 100 spp recorded in the region and the source of the information.

Riley, J. D., M. J. Andrews, M. W. Aprahamian and P. N. Claridge. 1986. Bass (*Dicentrarchus labrax*) year class size variation as shown by sampling the 0 group on power station cooling water intake screens, English coast 1972-1983. Annales Biologiques (Copenhagen). Vol. 40, pp. 181-

Robin, J. P. 1991. Assessment of Juvenile Flounder Catches at the Cordemais Power-Station Water-Intake in the Loire Estuary, France. Netherlands Journal of Sea Research, Vol. 27, No. 3-4, (Jul. 1991), pp. 317-323.

Abstract: A comprehensive sampling exercise was carried out at Cordemais Power Station during 1988 in order to evaluate the number of 0-group flounder, *Platichthys flesus*, removed from the Loire Estuary by the water intakes. Larvae drawn through the cooling system and juveniles impinged on the drumscreens were both taken into account. Statistical confidence limits of the estimates (which are useful for comparisons with the effect of other human activities) were estimated using non-linear regression and Monte-Carlo techniques. The method was developed for one of the two similar units working during the April-June period of high flounder abundance in the cooling-water. For this unit 16.5 million fish were drawn through the cooling system and 1.13 million were trapped on the drumscreen. The effect of the Power Station is discussed in connection with small-meshed fisheries and assessments of the estuarine juvenile stock.

Rodríguez Santiago, A. E. 2000. Taxonomic composition and seasonal abundance of zooplankton entrained by a thermoelectric power plant in San Juan Bay, Puerto Rico.

Rulifson, R. A. 1977. Temperature and water velocity effects on the swimming performances of young-of-the-year striped mullet (*Mugil cephalus*), spot (*Leiostomus xanthurus*), and pinfish (*Lagodon rhomboides*). J. Fish. Res. Board Can., Vol. 34, No. 12, pp. 2316-2322.

Abstract: Swimming performances of young-of-the-year *Mugil cephalus*, *Leiostomus xanthurus*, and *Lagodon rhomboides* were tested by examining the combination of physical endurance and swimming behavior to provide information on potential fish entrainment and impingement problems at industrial intakes. Tests were conducted at three temperatures (15-25 degree C) and six water velocities (12-48 cm/s). Fish lengths ranged from 1.4 to 7.0 cm TL. Fish tested at higher temperatures exhibited increased time for steady swimming and for impingement avoidance. Temperature was also positively correlated with maximum swimming speeds and with the number of bursts performed during drift-burst activity (drifting with the current and returning upstream with a burst of swimming). Increased water velocities resulted in decreased times of steady swimming and impingement avoidance, and reduced drift-burst activity. Larger fish avoided impingement longer and had faster maximum swimming speeds; however, smaller fish showed stronger rheotaxis and swam steadily for longer periods at equal water velocities. Abnormally heavy mullet and spot had reduced capabilities for position maintenance (steady swimming), which may decrease their ability to avoid impingement.

Saila, S. B. 1976. Final report on effects of power plant entrainment on winter flounder populations near Millstone Point. Narragansett, R.I.: Graduate School of Oceanography, University of Rhode Island.

Saila, S. B., E. Lorda, J. D. Miller, R. A. Sher and W. H. Howell. 1997. Equivalent adult estimates for losses of fish eggs, larvae, and juveniles at Seabrook Station with use of fuzzy logic to represent parametric uncertainty. North American Journal of Fisheries Management, Vol. 17, No. 4, (Nov. 1997), pp. 811-825.

Abstract: Regulatory agencies continue to direct their attention to the impact of coastal power generating stations on fishery resources. We analyzed 6 years of entrainment and 2 years of impingement data for selected species at the Seabrook Station, Seabrook, New Hampshire, in combination with selected life history parameters to provide equivalent adult estimates of fish losses at the station. The species examined were the winter flounder *Pleuronectes americanus*, pollock *Pollachius virens*, and red hake *Urophycis chuss*. The standard equivalent adult method involves estimates of numbers of fish entrained and impinged, survival from egg to impacted life history stage, and the average lifetime fecundity of a newly recruited female. However, this method does not account for the uncertainty in model parameters. The method was extended by applying fuzzy arithmetic to fuzzy numbers, constructed from empirical data, to provide upper and lower bounds on the estimated losses as equivalent adults. The analyses indicated that impingement losses were not ecologically significant for any of the three species. The largest equivalent adult losses were attributed to the entrainment of winter flounder larvae. However, even these represented an ecologically insignificant fraction of any sustainable stock. The offshore location of the intakes at mid-depth and the use of velocity caps were believed to account for the relatively small losses compared to similar coastal facilities. A specific comparison of equivalent adult estimates for winter flounder from another coastal power station (Pilgrim Station) indicated losses due to entrainment that were generally higher than for Seabrook Station.

Santos, C. 1985. Zooplankton entrainment evaluation in a power plant station. Coastal Zone. Vol. 1985, No. 2, pp. 2305-2312.

Schlotterbeck, R. E. and D. W. Connally. 1982. Vertical stratification of three nearshore southern California larval fishes (*Engraulis mordax*, *Genyonemus lineatus*, and *Seriphus politus*). Fishery Bulletin, Vol. 80, No. 4, pp. 895-902.

Abstract: Northern anchovy, *Engraulis mordax* (Engraulididae); white croaker, *Genyonemus lineatus* (Sciaenidae); queenfish, *Seriphus politus* (Sciaenidae) are among the most abundant adult fishes in the area, and are important links in the local trophic structure. Larval length-frequency distributions of the three species of fish were determined in conjunction with a study of the effects of a power plant offshore cooling-water intake on local nekton populations. The northern anchovy is important as forage for larger fishes and is fished commercially for manufacture of fish meal and oil. While the two sciaenid species have less commercial value, both are important as forage for larger species.

Schneider, J. W., B. J. Copeland and R. J. Monroe. 1980. The vertical distribution of estuarine meroplankton in the vicinity of a power plant cooling water intake, Southport, North Carolina. Raleigh, N.C.

Schubel, J. R., C. F. Smith and T. S. Y. Koo. 1977. Thermal effects of power plant entrainment on survival of larval fishes: a laboratory assessment. Chesapeake Sci., Vol. 18, No. 3, pp. 290-298.

Abstract: Blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), and striped bass (*Morone saxatilis*) larvae from the Chesapeake Bay region were subjected in the laboratory to time-excess temperature histories typical of those experienced by organisms entrained by power plants with a variety of design and operating criteria. The maximum excess temperature ranged from 7 degree to 20 degree C above the base temperature (the average surface water temperature on the spawning grounds); the time of exposure to a maximum excess temperature from 4 to 60 minutes; and the period of cooling to the final temperature from 60 to 300 minutes. An excess temperature of 20 degree C resulted in virtually total mortality of larvae of all 3 species. Striped bass larvae were the most tolerant of the 3 species and could withstand excess temperatures of up to 10 degree C with no significant increase in mortality. The response patterns of the other 2 species were more complicated.

Schubel, J. R., H. H. Carter and J. M. O'Connor. 1979. Effects of increasing [delta] T on power plant entrainment mortality at Indian Point, New York. Stony Brook, N.Y.: Marine Sciences Research Center, State University of New York.

Shao, K-T. and S-R. Kuo. 1988. Species composition and seasonal distribution of impinged fishes at the two intakes along the northern coast of Taiwan. Acta Zoologica Taiwanica. Vol. 1988, No. 2, pp. 209-227.

Shao, K-T., C-P. Lin, L-T. Ho and P-L. Lin. 1990. Study on the fish communities from northern and southern waters of Taiwan by analyzing the impingement data. Journal of the Fisheries Society of Taiwan, Vol. 17, No. 2, pp. 73-90.

Abstract: Fish impingement data collected from the cooling-water intakes of the three nuclear power plants located along the coast of northern and southern tips of Taiwan from July 1987 through June 1989 were used to analyze their species composition, temporal and spatial variations of fish communities. A total number of 84 families and 295 species of fishes were collected by systematic sampling method during the past two years. Among them, 113 species were economic species, which comprised 38.3%; 180 species were coral reef fishes contained 61% of the total species. However, 94.13% of the total impinged weights was contributed by economic species, mostly seasonal pelagic or benthic migratory species. The seasonal high peak of impingement in summer and low catches in winter were consistent among the three different stations especially for the economic species.

Sheng, L., W. Hou, G. Zhao, D. Li, X. Wang and S. Ru. 1994. Entrainment effect of power plant cooling system on young fish and postlarvae shrimp. Acta Scientiae Circumstantiae. (March. 1994), Vol. 14, No. 1, pp. 47-55.

Sissenwine, M. P., K. W. Hess and S. B. Saila. 1974. Interim report on evaluating the effect of power plant entrainment on populations near Millstone Point, Connecticut. Narragansett, R.I.: Graduate School of Oceanography, University of Rhode Island.

Sissenwine, M. P., K. W. Hess and S. B. Saila. 1974. Second semiannual report on evaluating the effect of power plant entrainment on populations near Millstone Point, Connecticut. Narragansett, R.I.: Graduate School of Oceanography, University of Rhode Island.

Stephens, J. S. Jr., P. A. Morris, D. J. Pondella, T. A. Koonce and G. A. Jordan. 1994. Overview of the dynamics of an urban artificial reef fish assemblage at King Harbor, California, USA. 1974-1991: A recruitment driven system. Bulletin of Marine Science, Vol. 55, No. 2-3, pp. 1224-1239.Note: This paper mentions "a significant annual mortality from adult fish entrapment and larval entrainment by the Southern California Edison (SCE) intakes".

Stewart, P. L. and S. H. Arnold. 1994. Environmental requirements of Atlantic herring (*Clupea harengus harengus*) in eastern Canada and its response to human impacts. Canadian technical report of fisheries and aquatic sciences, 46 pp.

Abstract: Atlantic herring (*Clupea harengus*) is a migratory species, returning to localized coastal areas and banks for spawning. Depending on stock and season, spawning occurs in shallow water as well as on deeper shoals and banks. Herring deposit eggs on the seabed in deeper water and on algae and solid substrate in shallow coastal spawning beds. Spawning areas are generally associated with well-mixed water, with tidal gyres, with estuaries having well-developed estuarine circulation, or in bays and other coastal features, which are believed to aid in keeping the larvae in the area for subsequent development and to permit development of schooling and migratory behavior. Herring can be affected by human activities. The tendency to school, the use of localized spawning and nursery areas, and the association of the species with coastal waters make herring more susceptible than many other species to accidental releases of contaminants. Herring can accumulate organic contaminants owing to their elevated lipid content; and although concentrations are small, they can lead to reduced reproductive success. Herring movements can be impacted by coastal structures, sea cages, entrainment in cooling-water from thermal power plants and from chlorine discharges used in fouling, as well as wastewater and sewage treatment.

Stupka, R. C. and R. K. Sharma, (year not available). Survey of fish impingement at power plants in the United States. Volume 3: estuaries and coastal waters. Argonne National Laboratory, IL (USA). Division of Environmental Impact Studies. Rep. Argonne Natl. Lab.

Abstract: Impingement of fish at cooling-water intakes of 32 power plants located on estuaries and coastal waters has been surveyed and data are presented. Descriptions of site, plant, and intake design and operation are provided. Reports in this volume summarize impingement data for individual plants in tabular and histogram formats. Information was available from differing sources such as the utilities themselves, public documents, regulatory agencies, and others. Thus, the extent of detail in the reports varies greatly from plant to plant. Histogram preparation involved an extrapolation

procedure that has inadequacies. The reader is cautioned in the use of information presented in this volume to determine intake-design acceptability or intensity of impacts on ecosystems. No conclusions are presented but data comparisons are made in Volume 4.

Swarbrick, S. L. and R. F. Ambrose. 1989. Technical report to the California Coastal Commission, C: Entrapment of juvenile and adult fish at SONGS. [Santa Barbara, CA]: The Committee.

Thomas, G. L. and R. L. Johnson. 1980. Density dependence and vulnerability of fish to entrapment by offshore-sited cooling-water intakes. Oceans '80. An international forum on ocean engineering in the '80s., Publ. by: IEEE; New York, NY (USA)., pp. 504-508.

Abstract: Simultaneous measurements of the offshore fish density and in plant fish entrapment were made during 8 surveys at 4 electric-generating stations along the Southern California coastline in 1979. Hourly estimates of the fish biomass in the vicinity of the cooling-water intake sites and measurements of fish entrapment were made. An entrapment vulnerability statistic, the ratio of the weight (kg) of fish entrapped in the plant (E) to the weight (kg) of fish offshore in the vicinity of the intake (B),i.e., E/B, was employed to describe the effect of water transparency, the velocity-cap and volume of flow on the entrapment of fish.

Thomas, G. L. 1980. A Field evaluation on the influence of the recirculation of cooling water (a heat treatment operation) on the entrapment of fish at Huntington Beach generating station. Seattle, Wash.: Fisheries Research Institute, College of Fisheries, University of Washington.

Titmus, G., P. N. Claridge and I. C. Potter. 1978. Growth and abundance of 0-group herrings, *Clupea harengus* L., in the Severn Estuary. Zool. J. Linn. Soc., Vol. 64, No. 3, pp. 251-260.

Abstract: Collections made from the cooling-water intake screens of Power Stations in the Severn Estuary and the Bristol Channel have been used to investigate the biology of 0-group herrings in this region. The abundance of herrings at Oldbury, the principal sampling site, was low in most years and in five successive seasons between July 1972 and Dec 1976, large numbers were caught only between the summer of 1975 and the spring of 1976. The herrings were first observed in July, when many had still not completed metamorphosis, and reached peak numbers in September and October during which period they were clearly growing. Numbers declined in Dec before rising dramatically in January at which time the length-frequency curves displayed a pronounced bimodality. On the basis of data from other parts of the Bristol Channel and Severn Estuary, it is suggested that this bimodality is due to the influx of some animals from other regions where the growth rate was greater. Although movement is apparently taking place at this time and the numbers decline markedly in subsequent months, the last remnants of the population do not leave the estuary until early May. Post-pelvic scute (KSUB-2) and vertebral counts (VS) of 13.82 and 55.24 respectively, indicate that the Severn Estuary herrings are the product of a spring spawning stock, a view entirely consistent with length and field data.

Turnpenny, A. W. H. and R. N. Bamber. 1983. The critical swimming speed of the sand smelt (*Atherina presbyter* Cuvier) in relation to capture at a power station cooling water intake. Journal of Fish Biology, Vol. 23, No. 1, pp. 65-73.

Abstract: (1) Critical swimming speeds (CSS) of sand smelt, *A. presbyter*, were measured in a laboratory flume. (2) Individuals of all age classes (0+ to 3+) found in the vicinity of Fawley Power Station, Hampshire, were tested at temperatures covering the seasonal range. (3) The median CSS was 2 multiplied by 7 body lengths per second (bl s super (-1)) at 5 multiplied by 8 degree C, rising to 5 multiplied by 7 bl s super(-1) at 18 multiplied by 5 degree C. (4) It is concluded that the sand smelt remains vulnerable to entrainment at the power station over its whole length range and over the full range of seasonal temperatures and that size-dependent swimming performance will not lead to significant bias in sample length distributions.

Turnpenny, A. W. H. 1983. Multiple regression analysis for forecasting critical fish influxes at power station intakes. Journal of Applied Ecology, Vol. 20, No. 1, pp. 33-42.

Abstract: (1) Coastal power stations in Britain are subject to ingresses of fish which, may jeopardize plant operation or temporary local depletion of fish populations. (2) There have been attempts in the United States and in Europe to develop costly and often ineffectual exclusion devices. For sites where the problem is intermittent, statistical models should be developed which allow critical levels of fish ingress to be predicted and the necessary reduction in cooling-water flow determined. (3) The procedure for developing a multiple regression model is described and illustrated using fish impingement data collected from Fawley Power Station. Over 60% of the overall variation was accounted for in terms of a small number of easily measured variables. With refinements of the model the approach would have practical application.

Turnpenny, A. W. H. 1988. Fish impingement at estuarine power stations and its significance to commercial fishing. Journal of Fish Biology, Vol. 33, pp. 103-110.

Abstract: The abstraction of cooling water (CW) at power stations sited on tidal waters inevitably leads to mortalities of some fish which are drawn in with the CW supply and become impinged on the intake screens. These fish are predominantly 0- or 1-group juveniles, which, owing to their small size, are unable to resist intake currents. Commercial fishermen often object to the fact that juvenile fish are killed in this way. Their concern stems from the fact that in order to protect stocks, commercial fishing is restricted to fish, which are above a statutory minimum landing size, whereas the majority of fish killed by impingement are below this size. This Report considers the significance of impingement mortalities at four estuarine sites in Britain for six commercially important species. Life tables are used to establish expected survival trajectories for each species and to compute reproductive potential. Each fish killed on intake screens is then considered in terms of the fraction of the reproductive potential of a single adult at maturity, and is ascribed an `adult equivalent' value. Total catches of mixed juveniles and adults are then presented as `adult equivalent' values.

Turnpenny, A. W. H., R. N. Bamber and P. A. Henderson. 1981. Biology of the Sand-Smelt (*Atherina presbyter* Valenciennes) around Fawley Power Station. Journal of Fish Biology, Vol. 18, No. 4, pp. 417-427.

Abstract: (1) Past studies of fish impingement at Fawley power station have shown that sand-smelts, *Atherina presbyter* Valenciennes, are susceptible to impingement and may be a useful species for examining effects of impingement mortalities on population size and structure. (2) A 21 month study of population in the vicinity of Fawley power station was carried out to obtain data on the biology of the species for future population dynamics modelling studies. (3) Aspects included in the study were growth, sex ratio, reproduction, survival and mortality rates and diet.

Ulanowicz, R. E., J. M. Lindsay and W. C. Caplins. 1982. Simulating the Lateral Transport of Ichthyoplankton in the Potomac Estuary. Estuaries, Vol. 5, No. 1, pp. 57-67.

Abstract: (1) Previous simulations of potential ichthyoplankton entrainment by power generating stations on the Potomac estuary have not included the influence of lateral transport in distributing eggs and larvae over the nursery area. Therefore, two-dimensional, vertically-averaged hydrodynamic and kinematic models of passive organism transport were developed to represent advective and dispersive processes near the proposed Douglas Point Nuclear Generating Station. (2) Although the more refined model did not substantially alter the estimate of ichthyoplankton entrainment, it did reveal that lateral inhomogeneities in hydrodynamics could engender several fold differences in entrainment probabilities on opposite sides of the estuary. (3) Models of higher resolution and greater biological detail did not project greater total entrainment by the Douglas Point plant, because the volume of nontidal flow past the site was large in comparison to the proposed rate of cooling-water withdrawal.

Uziel M. S. 1978. Impingement. Journal Water Pollution Control Federation, Vol. 50, Iss. 6, pp. 1553-1567.

Uziel M. S. 1980. Entrainment And Impingement at Cooling Water Intakes. Journal Water Pollution Control Federation, Vol. 52, Iss. 6, pp. 1616-1630.

Van Winkle, W. 1980. Evaluation of impingement of losses of white perch at the Indian Nuclear Station and other Hudson River power plants. Washington, D.C.: Springfield, Va.: The Commission: Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission ; National Technical Information Service.

Vandenbroek, W. L. F. 1979. A seasonal survey of fish populations in the Lower Medway Estuary, Kent, based on power station screen samples. Estuar. Coast. Mar. Sci., Vol. 9, No. 1, pp. 1-15.

Abstract: Quantitative samples were collected from the cooling-water intake screens at Kingsnorth Power Station between May 1973 and Aug 1975. The sampling method is discussed and the catch compared with trawl samples taken in the vicinity. A total of 46,228 fish, 49 species and weighing 325.0 kg were taken in 39 screen samples.

Numerically the monthly samples were dominated by *Sprattus sprattus* and twelve other species, which together formed more than 90% of the catch in most months. Short-term fluctuations in catch were marked but superimposed on this was a clear seasonal cycle; numbers of species, numbers of individuals and total weights of catch reached maximum in winter and minimum in summer. The three diversity indices measured displayed no definite seasonal pattern, the result of fluctuations in sprat numbers.

Vaughan, D. S., N. Buske and S. B. Saila. 1976. Final report on evaluating the effect of power plant entrainment on populations near Millstone Point, Connecticut (Menhaden). Narragansett, R.I.: Graduate School of Oceanography, University of Rhode Island.

Victor-Baptiste, F. and C. Wohrer-Blanpied. 1983. Quantitative and qualitative estimation of impinged fishes at the Gravelines nuclear plant. Oceanis. Serie de documents oceanographiques (Paris), Vol. 9, No. 1, pp. 33-52.

Abstract: The purpose of this study at the Gravelines nuclear plant (Northern France) was to estimate the impact of coastal nuclear plants on fish populations. The study was made in relation to fish mortality due to impingement and the egg and larvae mortality after their transit into the water-cooling system. This quantitative and qualitative estimation of impinged fishes is based on weekly samples. The sampling method, early results and a preliminary analysis of the factors capable of affecting this impingement are described here.

Weisberg, S. B. 1984. The effects of screen slot size, screen diameter, and through-slot velocity on entrainment of estuarine ichthyoplankton through wedge-wire screens. Annapolis, Md.: Maryland. Dept. of Natural Resources, Power Plant Siting Program.

Weisberg, S. B., W. H. Burton, F. Jacobs and E. A. Ross. 1987. Reductions in ichthyoplankton entrainment with fine-mesh, wedge-wire screens. North American Journal of Fisheries Management, Vol. 7, No. 3, pp. 386-393.

Abstract: The exclusion efficiency of cylindrical wedge-wire screens was investigated at the Chalk Point Steam Electric Station in Aquasco, Maryland, by measuring entrainment of larval bay anchovies *Anchoa mitchilli* and naked gobies *Gobiosoma bosci* through screens with slot sizes of 1, 2, and 3 mm and through an unscreened intake. The degree of exclusion by the screens increased with fish size. Fish less than 5 mm long were not excluded by any of the screens. In contrast, more than 80% of larger ichthyoplankton were excluded by all screens. Virtually no ichthyoplankton larger than 10 mm were entrained through the 1-mm screen even when fish of this size were abundant and were entrained through the unscreened intake. The results suggest that entrainment through water intake structures can be successfully reduced by wedge-wire screens if the larval fish at risk exceed 5 mm in length.

Wharfe, J. R., S. R. Wilson and R. A. Dines. 1984. Observations on the fish populations of an east coast estuary. Marine Pollution Bulletin, Vol. 15, No. 4, pp. 133-136.

Abstract: (1) Monthly samples of fish were collected from the cooling-water intake screens at Kingsnorth Power Station on the Medway Estuary. (2) A total of 26,372 fish,

comprising 41 species, was recorded between April 1981 and August 1983. (3) The seasonal distribution of both species numbers and abundance of fish was similar to earlier studies, although the community structure has altered in recent years. (4) The regular occurrence and increased population size of *Osmerus eperlanus*, the smelt, and *Clupea harengu*s, the herring, were the most notable changes. (5) The results are compared with previous studies, and the indirect effects of enhanced water quality conditions in the tidal Thames and the subsequent recolonization by fish, which were previously absent for many years, are discussed.

Zheng, C., Z. Huang, C. Li, J. Wang and S. Lin. 1990. Filtering substances from cooling water filtration gate and drum of Daya Bay Nuclear Power Station. Collections of Papers on Marine Ecology in Daya Bay (2)., Dayawan Haiyang Shengtai Wenji (2). 1990, pp. 497-505.

Abstract: A weekly survey was carried out on the filtering substances of cooling-water system for 24 h at 3 h intervals at the cooling-water intake of GNPS, Daya Bay, China in 1987, totaling 52 cruises with 412 net trawlings. The results indicate that there were minorly abiotic materials, and mainly sargassum medusa, opossum shrimp and fishes. These organisms presented clear seasonal and day/night variations. Sargassum occurred especially in large quantities from March to April and reached nearly zero in summer. Opossum shrimps mainly appeared at night.

## PART II: STUDIES RELATED TO ASSESSMENT OF FISH IMPINGEMENT/ENTRAINMENT BY COOLING-WATER INTAKES

Anon. 1983. Mathematical modeling of estuarine phenomena. Hydro Delft, No. 67, pp. 3-8.

Abstract: Estuarine research is a difficult job for which often still complex hydraulic scale models are used. However, the development of mathematical modeling techniques made it possible to tackle gradually more estuarine problems. The basis for these studies are mathematical models describing the water movement in the system. One-dimensional models are being applied already quite some time, but although they are cheap in use, their applicability is limited. They cannot simulate density-induced currents properly, while also most estuaries have a complex geometry. Therefore, a proper simulation of estuarine flows calls for two-dimensional modeling in the vertical sense in case of a stratified system or in the horizontal sense in the case of a well mixed wide estuary with tidal flats and deep channels. Data from these models simulating the hydraulics, can be used as an input for models of the influence of infrastructural works, salt intrusion, the effect of waste discharges, the water quality, cooling-water recirculation and sediment transports. The work in these fields is illustrated.

Attrill, M. J., M. Power and R. M. Thomas. 1999. Modelling estuarine Crustacea population fluctuations in response to physico-chemical trends. Marine Ecology Progress Series, Vol. 178, pp. 89-99. Mar 1999.

Abstract: Regular samples (generally every 2 wk) of 6 estuarine crustacean species, *Carcinus maenas*, *Liocarcinus holsatus*, *Crangon crangon*, *Palaemon longirostris*, *Palaemon serratus* and *Gammarus spp*. (mainly *G. zaddachi*), were taken over a 12 yr period from the cooling-water intake screens of West Thurrock power station on the Thames estuary, UK. Additionally, comparative data sets for abiotic variables (freshwater flow, salinity, temperature, dissolved oxygen, pH, suspended solids, total nitrogen) were collected for the same time period. The comprehensive nature of the time series, and accompanying suite of variables, allowed the construction of statistical models for the trends in population abundance of the 6 species using multiple linear regression techniques. Statistically significant models were constructed for *C. maenas*, *C. crangon* and *Gammarus spp*., accurately predicting annual, and longer term, fluctuations in abundance. All models had strong seasonal components, although for *C. maenas* temperature was the only physico-chemical variable with significant explanatory power. The importance of temperature as a controlling variable for the species was reinforced by the inclusion of an instrumental variable to simulate a threshold temperature for foraging activity. The optimal value was found to be 8 ºC. *C. crangon* was found to be positively correlated with dissolved oxygen, but showed a slight decline in abundance over the time period. There was no significant relationship with either salinity or temperature, variables previously suggested as being important. *Gammarus spp*. abundance had 2 significant explanatory variables (temperature and salinity) but also demonstrated a large decrease in population size with time. *L. holsatus* and *P. serratus* are summer-occurring species, so were recorded too infrequently to adequately capture seasonal dynamics.

Despite the long time series, no significant model was possible for *P. longirostris* abundance (non-normal residuals), which has been suggested previously as having a strong relationship with salinity. The results of the study provide the first significant multiple linear regression models that accurately predict estuarine crustacean abundance. Whilst these models are useful for helping to understand variability in the Thames, it will be interesting to determine whether populations in other estuaries demonstrate relationships with similar suites of physico-chemical parameters.

Barnthouse, L. W., D. L. DeAngelis and S. W. Christensen. 1979. An empirical model of impingement impact / Washington, D.C.: Springfield, Va.: The Commission ; Available from National Technical Information Service.

Boreman, J., C. P. Goodyear and S. W. Christensen. 1981. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. Transactions of the American Fisheries Society. Vol. 110, No. 2, pp. 253-260.

Cakiroglu, C. and C. Yurteri. 1998. Methodology for predicting cooling water effects on fish. Journal of Environmental Engineering, Vol. 124, No. 7, pp. 612-618. (Jul 1998).

Abstract: The mathematical model presented here predicts the long-term effects of once-through cooling-water systems on local fish populations. The fish life cycle model simulates different life stages of fish by using appropriate expressions representing growth and mortality rates. The heart of the developed modeling approach is the prediction of plant-caused reduction in total fish population by estimating recruitment to adult population with and without entrainment of ichthyoplankton and impingement of small fish. The model was applied to a local fish species, gilthead (*Sparus aurata*), for the case of a proposed power plant in the Aegean region of Turkey. The simulations indicate that entrainment and impingement may lead to a population reduction of about 2% to 8% in the long run. In many cases, an impact of this size can be considered rather unimportant. In the case of sensitive and ecologically valued species facing extinction, however, necessary precautions should be taken to minimize or totally avoid such an impact.

Christensen, S. W. and D. L. DeAngelis. 1982. The effect of stochastic variation on estimates of the probability of entrainment mortality: Methodology, results, and user's guide. NTIS, Springfield, VA (USA), 82 pp.

Abstract: The probability that live fish eggs or larvae, entrained in cooling water, will be killed is an important element in projecting power plant effects on fish stocks. This probability, the entrainment mortality factor, is commonly estimated with one of several relatively simple formulae, which use data collected from intake and discharge water. Such biological phenomena as gear avoidance, gear-induced mortality, extrusion through nets, and the presence of dead organisms in ambient water introduce errors into estimates obtained with these formulae. An additional difficulty is that, because of small sample sizes, it is usually necessary to combine data from many samples, taken under different conditions, before applying the formula.

Coutant, C. C., R. B. McLean and D. L. DeAngelis. 1979. Influences of physical and chemical alterations on predator-prey interactions. Predator-Prey Systems In Fisheries Management, pp. 56-68.

Abstract: Three facets of identifying influences of physical and chemical alterations on predator-prey interactions are described: 1) experimental research; 2) field studies; and 3) computer simulation for making predictions based on research data. Detailed experimental research is beginning to be applied to the question of sub-lethal stresses that affect predator-prey interactions. Engineering works such as power station water intakes can act as "predators" on forage species in competition with natural, biotic predators. Computer modeling was used to show that small differences in growth rates of two species of fish fry can determine whether there is significant interspecies predation and whether the slower-growing species could be eliminated. Predator-prey interactions in nature probably do more to determine the species composition of water bodies than could all of man's direct fish kills. The subtle stresses and changes man imposes on those predation relationships are likely the vehicles for many of the changes seen in aquatic ecosystems over the years. Only by understanding these subtle impacts, and by determining "tolerance thresholds" of aquaticpopulations for them, aquatic life resources can be managed.

Cowan, C. E. 1977. A methodology for determining the effects of fish characteristics on the entrainment of larval fish. Thesis/dissertation/manuscript.

DeAngelis, D. L., S. W. Christensen and A. G. Clark. 1977. Responses of a fish population model to young-of-the-year mortality. J. Fish. Res. Board Can., Vol. 34, No. 11, pp. 2124-2132.

Abstract: A multiple-age-class model is used to examine the effects of increases in density-independent young-of-the-year mortality caused by power plant entrainment of larval fish. It is demonstrated analytically that in all realistic cases, an increase in such mortality results in a smaller equilibrium population density of adult fish. The stability of the population with respect to perturbations about its equilibrium point is increased in these cases. However, situations can occur where a slight increase in mortality causes a catastrophic population decline. The model is used to generate autoregression graphs of population numbers that can be compared with field data.

Dunstall, T. G. 1980. Approaches Used to Assess the Impact on Fish Populations Resulting From Power Station-Induced Mortality - A Review. Rep. Ont. Hydro Res. Div. (Can.), 16 pp.

Abstract: Approaches taken to evaluate the significance of fish loss at generating stations employing once-through cooling were reviewed. Population models have been used to describe reduction in abundance of fish stocks resulting from entrainment at thermal generating stations. These models are based on life history strategies of the species. Required estimates of initial population size and per cent reduction of young-of-the-year fish limits the use of life cycle models to populations of known stock size. An approach equating ichthyoplankton entrainment losses to adult fish required to maintain the

populations in equilibrium is more general in application. Community level assessments require estimation of fish biomass removed from the ecosystem by generating station operation.

Eisele, P. J. and J. F. Malaric. 1978. A conceptual model of causal factors regarding gizzard shad runs at a steam electric power plant. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York, Publ. by : EA Communications; Melville, NY (USA) (Apr 1978), pp. 291-298.

Abstract: Gizzard shad runs are a common yet seemingly unpredictable event occurring during cool weather at power plant intakes. Both young-of-the-year and adult shad are involved. Various environmental parameters were measured during three years of continuous fish collection using a fish pump at the Monroe Power Plant. Parameters include power plant operating conditions, water quality, and weather conditions. These parameters were used in regression analysis to determine their effect on shad runs. A conceptual model is presented to identify the causal relationships.

Electric Power Research Institute. 1999. Catalog of Assessment Methods for Evaluating the Effects of Power Plant Operations on Aquatic Communities, EPRI, Palo Alto, CA, Report TR-112013, (May 1999), 302 pp.

Abstract: This report documents the current state of knowledge on methods for assessing the effects of stressors on the health, function, integrity and quality of aquatic populations and ecosystems. This information will be valuable to industry, resource agencies, non-governmental environmental organizations, and universities involved in research, management and protection of aquatic resources.

Electric Power Research Institute. 2000. Evaluation of Biocriteria as a Concept, Approach and Tool for Assessing Impacts of Entrainment and Impingement under Section 316(b) of the Clean Water Act, EPRI, Palo Alto, CA, Report TR-114007, (Aug 2000), 152 p.

Abstract: This report documents the current state of development of multimetric bioassessment and biocriteria for assessing the biological integrity of aquatic ecosystems. The report also examines the suitability of multimetric bioassessment for regulating cooling-water intake structures (CWIS) under Section 316(b) of the Clean Water Act (CWA). This report will be valuable to industry, resource agencies, non-governmental environmental organizations, and universities involved in research, management, and protection of aquatic resources.

Electric Power Research Institute. 2002. Assessment of Spawning and Nursery Habitat: Review and Evaluation of Methods Potentially Applicable to Regulation of Cooling water Intake Structures, EPRI, Palo Alto, CA, Report 1000732. (Feb 2002).

Abstract: Spawning and nursery habitat assessments can influence the regulation of cooling-water intake structures (CWISs) under Section 316(b) of the Clean Water Act. This report documents the state of development of methods for assessing fish spawning

and nursery habitats, examining the suitability of such methods for regulating CWISs under Section 316(b).

Electric Power Research Institute. 2002. Evaluating the Effects of Power Plant Operations on Aquatic Communities: An Ecological Risk Assessment Framework for Clean Water Act Section 316(b) Determinations, EPRI, Palo Alto, CA, Report 1005337. (Jul 2002).

Abstract: This report describes a general framework for ecological risk assessment proposed by the U. S. Environmental Protection Agency (USEPA) and explains how this framework can be integrated into the decision-making process under Section 316(b) of the Clean Water Act (CWA). This report complements EPRI reports TR-112013 and 1005176. These three reports provide technically sound guidance for assessing the potential for adverse environmental impact (AEI) resulting from cooling-water withdrawals and evaluating the potential ecological benefits of mitigation alternatives.

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

Abstract: This report provides guidelines for selecting methods to estimate effects of cooling-water withdrawals on aquatic populations and communities. The report is a companion to the EPRI 1999 report TR-112013, "Catalog of Assessment Methods for Evaluating Effects of Power Plant Operations on Aquatic Communities." These two documents describe approaches for estimating the magnitude of cooling-water intake structure effects as part of assessing the potential for adverse environmental impact (AEI) under Section 316(b) of the Clean Water Act (CWA).

Fletcher, R. I. 1985. Risk analysis for fish diversion experiments: Pumped intake systems. Transactions of the American Fisheries Society, Vol. 114, No. 5, pp. 652-694.

Abstract: Such facilities as power-generating stations, public water systems, and re-processing plants draw off large quantities of water from estuaries, coastal seawaters, lakes, and rivers. In turn, large numbers of fishes are often drawn into these pumped intake systems and killed if not otherwise removed or diverted. The large mortalities associated with many intake systems treated the perpetuation of indigenous stocks. The diversion and removal devices most commonly used for protecting fish life from such risks are presumed to operate on principles shown here to be erroneously conceived. In consequence of these faulty theories, the estimators and experimental designs of standard industry practice seldom reveal the true correlations necessary for improvements in fish conservation systems, nor do the assessments of small-scale experiments extend with reliability to full-scale system designs.

Goodyear, C. P. 1977. Mathematical methods to evaluate entrainment of aquatic organisms by power plants. [Washington, D.C.]: Power Plant Project, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior.

Goodyear, C. P. 1978. Entrainment impact estimates using the equivalent adult approach. [Washington]: The Service: for sale by the Supt. of Docs., U.S. Govt. Print. Off.

Gray, R. H., T. L. Page, D. A. Neitzel and D. D. Dauble. 1986. Assessing population effects from entrainment of fish at a large volume water intake. J. Environ. Sci. Health, Part A., Vol. 21a, No. 2, pp. 191-209.

Abstract: The authors describe a method for estimating population effects from entrainment of juvenile chinook salmon (*Oncorhynchus tshawytscha*) at a steam electric generating station on the Columbia River that required cooperation between power plant operators and fishery biologists. The method involved sampling fish in the river and entrained fish (both marked recaptures and naturally occurring downstream migrants) within the intake, and estimating the total number of fish entrained, size of the natural population, and percent of the natural population affected.

Hackney, P. A. 1980. A partial differential equation model of fish population dynamics and its application in impingement impact analysis / Research Triangle Park, N.C.: Springfield, Va. : U.S. Environmental Protection Agency, Office of Research and Development, Industrial Environmental Research Laboratory ; available from National Technical Information Service.

Hackney, P. A. 1977. Methods for calculating natural mortality rate, biomass production, and proportion entrained of lacusterine Ichthyoplankton. In: Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 3-6, 1977.

Abstract: The impact of ichthyoplankton entrainment in lacusterine environments has been difficult to ascertain because the total number produced is usually unknown. Additionally, larvae in lakes are vulnerable to entrainment for varying periods of time, not just instantaneously as when transported past cooling-water intakes located on rivers. A method for determining the number of larvae produced in lakes is given. Also, methods of calculating the natural mortality rate and biomass production of lacusterine ichthyoplankton are presented.

Helbig, J. and P. Pepin. 1998. Partitioning the influence of physical processes on the estimation of ichthyoplankton mortality rates. I. Theory. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 55 (October 1998), pp. 2189-2205.

Hess, K. W., M. P. Sissenwine and S. B. Saila. 1975. Simulating the impact of the entrainment of winter flounder larvae. Fisheries and energy production: A symposium.

Abstract: The transport of winter flounder larvae around the Millstone Point, Conn. Area by the action of tidal currents and diffusion was simulated by computer to predict the numbers, which could be entrained during the operation of a local nuclear power station. A tidal hydrodynamic model with variable depth was employed to simulate currents and water levels. These techniques provided input to a transport model which simulated the conc. of larvae. A larval source in a tributary river was simulated for twenty tidal cycles, with and without entrainment. The results indicated that the reduction in winter flounder larvae near Millstone Point at the end of the pelagic stage (period during which larvae are likely to be entrained) was less than 1% when it was assumed that larvae have little chance of returning once lost from Millstone bight. In

order to assess the effect of a 1% reduction in recruitment of winter flounder larvae to the benthic phase of their life cycle, the local population was simulated by a model in which year-classes and the total egg production were represented by compartments. Each year-class grew, produced eggs, suffered natural and fishing mortality according to information derived from the literature. The effect of power plant entrainment was incorporated by reducing the number of recruits to year-class I that would normally result from a specific level of egg production. For a 1% reduction in recruitment due to power plant entrainment, a potential 6% decrease in total population size following 35 y of operation was indicated.

Jager, H. I., D. D. Schmoyer, M. J. Sale, W. Van Winkle and D. L. DeAngelis. 1993. A spatial simulation of small mouth bass in streams. CONF-930870-1, 11 pp.

Abstract: The hydropower industry and its regulators are hampered by the inability to predict the relationship between alternative flow regimes and fish population response. We have developed a spatially explicit, individual-based model of populations of small-mouth bass in streams as part of the Compensatory Mechanisms in Fish Populations Program. In the model, the profitability of alternative stream locations varies in response to habitat depth and velocity through changes in the frequency of prey encounters and the metabolic costs experienced by fish. We conducted an evaluation of our hydraulic simulation at the scale of individual stream cells. The potential error in predictions for individual cell velocities suggests that larger-scale model predictions for the representative reach are most appropriate. At this scale, the model appears to produce realistic patterns in the growth and dispersal of young-of-year small-mouth bass. This verification step allows us to proceed with greater confidence in evaluating the original question of how small-mouth bass populations respond to alternative flow regimes.

Jeffries, P., A. Keller and S. Hale. 1989. Predicting winter flounder (*Pseudopleuronectes americanus*) catches by time series analysis. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 46, No. 4, pp. 650-659.

Abstract: Long-term changes in catches of winter flounder (*Pseudopleuronectes americanus*) were compared at five locations within Narragansett Bay, Rhode Island, USA and in three areas directly offshore. In the lower Bay, relative abundance decreased 86% during warming in the early 1970's,recovered briefly, and then declined to an all-time low in 1986.Time-series analysis successfully predicted a recovery in 1987. Year ahead predictions, based on annual models, had a maximum error of 14% (1986); monthly forecasts explained 62-72% of catch variation during the entire investigation; cumulative monthly error (forecast compared with actual over an annual cycle) was 11% in the Bay and 21% offshore. Commercial offshore catch and the fish retained on power plant intake screens in two major rivers showed the same 11-yr pattern of population fall and recovery detected in the lower Bay.

Jensen, A. L. 1990. Estimation of recruitment forgone resulting from larval fish entrainment. Journal of Great Lakes Research, Vol. 16, No. 2, pp. 241-244.

Abstract: The effect of larvae entrainment on fish populations is difficult to determine because larvae abundance, mortality, and growth are difficult to estimate. The concept of

production forgone (lost) was developed recently to avoid estimation of abundance, but estimates of mortality and growth rates for larvae, young-of-year, and juveniles are still necessary, and these too are difficult to estimate. For sportfish, production forgone is less important than recruitment, and recruitment forgone, or lost, as a result of larvae and egg entrainment could be useful for assessment of sportfish larvae and egg entrainment. A method is developed for estimation of recruitment forgone; it only requires estimates of population parameters for the mature population; it requires no estimates of abundance. The method is applied to assess yellow perch larvae entrainment at the Monroe Power Plant, Monroe, Michigan, located on the western basin of Lake Erie.

Jensen, A. L. 1982. Impact of a Once-Through Cooling System on the Yellow Perch Stock in the Western Basin of Lake Erie. Ecological Modelling, Vol. 15, No. 2, pp. 127-144.

Abstract: The surplus production model, a conventional fishery stock assessment model, is applied to assess the entrainment and impingement impact of the Monroe Power Plant on the yellow perch (*Perca flavescens*) standing stock and fishery in the western basin of Lake Erie. Biological parameters of the model are estimated from commercial catch and effort data and entrainment and impingement coefficients are estimated from power plant data. The model is applied to estimate stock biomass, egg production, and larva production; the proportions entrained and impinged are then estimated. The impact of water withdrawal on the equilibrium standing stock and maximum sustainable yield from the fishery is estimated and the impact of increased water withdrawal is simulated. The impact on equilibrium standing stock and the maximum sustainable yield are larger than the proportion of the standing stock entrained and impinged, but the impact of the Monroe Power Plant is relatively small; it decreases biomass and the maximum sustainable yield of the yellow perch stock by only a few percent. However, there are several power plants impacting the yellow perch stock of the western basin of Lake Erie and the combined impact should be examined.

Jensen, A. L. 1992. Relation between mortality of young walleye (*Stizostedion vitreum*) and recruitment with different forms of compensation. Environmental Pollution, Vol. 76, No. 2, pp. 177-181.

Abstract: The relation between mortality of young fish and recruitment is important for assessment of the environmental effects of facilities that kill large numbers of young fish, such as electric power stations and hydropower plants. A simulation model with a bioenergetic growth component was applied to examine the relation between mortality of young and recruitment for walleye (*Stizostedion vitreum*) with different forms of population regulation, including: food limited growth, food limited growth with size-dependent mortality, and food limited growth with age at maturity dependent on size. With food limited growth small increases in mortality of young reduced recruitment considerably, but the population slowly approached a new equilibrium. If mortality of young increased when growth was food limited, the population approached a new equilibrium of natality and mortality because with fewer individuals there was more food per individual, and individuals were larger in size and produced more eggs; this feedback adjusted natality to equal mortality. With either mortality or age at maturity dependent

on size, large increases in mortality of young resulted in only small decreases in recruitment.

Jensen, L. D. 1974. Entrainment and intake screening: Proceedings of the Second Entrainment and Intake Screening Workshop. Palo Alto, Calif.: Electric Power Research Institute.

Jensen, L. D. 1981. Issues associated with impact assessment: proceedings of the Fifth National Workshop on Entrainment and Impingement, Sheraton-Palace, San Francisco, California, 5-7 May 1980. Sparks, Md.: EA Communications.

Johnson, G. E., J. R. Skalski and D. J. Degan. 1994. Statistical precision of hydroacoustic sampling of fish entrainment at hydroelectric facilities. North American Journal of Fisheries Management, Vol. 14, No. 2, pp. 323-333.

Abstract: Hydroacoustic sampling can be an important technique for estimating fish entrainment rates at hydroelectric facilities applying for relicensing by the U.S. Federal Energy Regulatory Commission. Existing sampling procedures typically require daily monitoring of entrainment over at least one annual cycle. To investigate potential cost savings through the use of probability sampling, three data sets consisting of daily hydroacoustic estimates of entrainment for at least 1 year were reanalyzed to determine the effects of subsampling on the precision of seasonal and annual estimates of fish entrainment. The study sites were located in New York, Wisconsin, and annual estimates of fish entrainment. The study sites were located in New York, Wisconsin, and South Carolina. When a stratified random sample of days within each month was used, a 50% subsample of days (i.e., 15 d/month) resulted in a sampling precision of approximately plus or minus 22.0% of the true value of annual entrainment at the New York site, plus or minus 14.3% at Wisconsin, and plus or minus 9.6% at South Carolina, 95% of the time. Sampling 20 d/month resulted in a precision of plus or minus 15.5%, plus or minus 10.0%, and plus or minus 6.7%, respectively, 95% of the time. Substantial cost savings appear possible through the use of stratified random sampling designs that provide a level of precision sufficient for both management and relicensing decisions.

Kaluzny, S. P., K. A. Rose, P. J. Sullivan and G. L. Swartzman. 1983. Evaluation of ecosystem models in power plant impact assessment: A case study using Lake Ontario. Description of alternative process equations and documentation of parameters values. WU, SEATTLE, WA (USA), 66 pp.

Abstract: In this report, the authors give the documentation for LAKONT, multi-trophic level model for energy flow and population dynamics in the neighborhood of the Nine Mile Point and Fitzpatrick nuclear power stations. The model contains equations from models reviewed from the literature and is designed to compare the behavior of models put together with different combinations of the reviewed equations. Here they give the equation forms and rationale, a description of the biotic and spatial structure of the models, a list of notation and parameter values and reference to the sources of data used to estimate parameter values and run the model.

Kimmerer, W. J., J. H. Cowan Jr., L. W. Miller and K. A. Rose. 2001. Analysis of an Estuarine Striped Bass Population: Effects of Environmental Conditions During Early Life. Estuaries, Vol. 24, No. 4, pp. 557-575, (Aug 2001).

Abstract: Estuarine fish populations are exposed to a variety of environmental conditions that cause both short-term variability and long-term trends in abundance. We analyzed an extensive data set for striped bass (*Morone saxatilis*) in the San Francisco Estuary to refine our understanding of how environmental variability influences recruitment. We examined the effects of environmental variability during early life stages on subsequent recruitment (age 3 yr), and the degree to which conditions in early life may have contributed to a long-term decline in abundance of adult striped bass in the San Francisco Estuary. Survival from egg to young-of-the-year varied strongly with freshwater flow; this effect apparently occurred within the first week or two of life, a time period that encompasses transport of eggs and larvae from the rivers to rearing areas and the onset of feeding. The rate of freshwater flow to pumping facilities that export freshwater from the system had small or sporadic effects on survival during the first month or two of life. Although many young striped bass between ages 2 and 8 mo were entrained in export pumping facilities, the resulting high mortality was unrelated to total mortality rates determined from field data on young striped bass. This lack of effect was apparently due to strong density-dependent mortality occurring between ages 1 mo and 3 yr (Kimmerer et al. 2000). The available data do not support previously suggested relationships between recruitment and freshwater flow during early life, or between gross estimates of pesticide input and survival of early life stages. We used a simple life-cycle model to show that various combined factors could have led to a decline in adult abundance, particularly a large and increasing adult mortality, but that events early in life probably did not contribute substantially to the decline. These results demonstrate that several decades of monitoring data from numerous life stages are needed to distinguish among alternative hypotheses about environmental influences on populations of estuarine fish.

Kleinstreuer, C. and B. E. Logan. 1980. A mathematical model simulating fish losses near power plants using rotenone data. Water Res., Vol. 14, No. 8, pp. 1047-1053.

Abstract: Fish losses like impingement on cooling-water intake screens play an important role in the overall physical impact on the aquatic ecosystem by power-plant operations. Of the long list of potential causes for fish losses, 3 most significant factors are examined, i.e. fish population dynamics, water temperature and the hydrodynamics of the cooling-water body. A semi-empirical, comprehensive model has been developed employing inexpensively sampled site specific far-field data on which the submodels for flow patterns, temperature and fish population are based. These submodels are directly adaptable to other sites and alternative case studies; the population submodel, for example, could also be employed for investigating the impact of increased fish mortality caused by toxic materials, excessive fishing, etc. The comprehensive model together with the systems analysis approach presented can be used as a planning tool for the optimal design and location of proposed power plants and for the minimization of aquatic ecosystem impacts due to existing plants. The impingement model was successfully pplied to Arkansas Nuclear One (lake with long intake canal) and Browns Ferry (river with short intake canal).

Kumar, K. D. and J. S. Griffith. 1978. Temporally stratified sampling programs for estimation of fish impingement. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York, Publ. by: EA Communications; Melville, NY (USA)., (Apr 1978), p. 267-280.

Abstract: Impingement monitoring programs often expend valuable and limited resources and fail to provide a dependable estimate of either total annual impingement or those biological and physicochemical factors affecting it. In situations where initial monitoring has identified 'problem' fish species and the periodicity of their impingement, intensive sampling during periods of high impingement, will maximize information obtained. The authors use data gathered in a study of 32 generating facilities throughout the southeastern United States to discuss techniques of designing temporally stratified monitoring programs and their benefits and drawbacks. Of the possible temporal patterns within a calendar year, differences between seasons are most influential in the impingement of freshwater fishes in the Southeast. Data on the threadfin shad (*Dorosoma petenense*) and the role of seasonal temperature changes are used as an example to demonstrate ways of most efficiently and accurately estimating impingement of the species.

Lawler, J. P., T. L. Englert, R. A. Norris and C. B. Dew. 1977. Modeling of compensatory response to power plant impact. In: Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 3-6.

Abstract: Mechanisms of kinetics of compensatory response in fish populations subject to power plant cropping are presented. Topics discussed include (a) the biological and mathematical underpinning leading to nonlinear prey-predator and competitor relations; (b) the mathematical relationship between compensating and non compensating systems for single species cases; (c) the relationship between Ricker-type stock-recruitment, population oscillation, and lagged logistic growth; (d) the use of Ricker and Beverton-Holtstock-recruitment curves to simulate compensation in single-species lifecycle models; and (e) a model of density-dependent growth. Application of the last two topics to the assessment of power plant impact in the Hudson River is discussed.

Lifton, W. S. and J. F. Storr. 1978. The effect of environmental variables on fish impingement. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York, Publ. by EA Communications; Melville, NY (USA)., (Apr 1978), p. 267-280.

Abstract: Studies were conducted on two power stations to contrast the differences between two types of intake systems used. The C.R. Huntley Power Station is a fossil-fueled plant located near Buffalo, NY on the Niagara River. The plant employs a shoreline intake system. Studies conducted there showed statistically significant correlations between changes in several environmental variables (including wind speed, wind direction, sky cover, and water temperature) and fish impingement. These correlations indicated important relationships between physical factors and behavior of

fish species. These behaviors are triggered by wave action, turbulence, seiche, and changes in light intensity. Species studied included rainbow smelt, alewives, and gizzard shad. The R.E. Ginna Power Station is a nuclear plant with an offshore intake located near Rochester, NY, on Lake Ontario. The effect of environmental variables (including wind direction, wind speed, sky cover, and water temperature) on fish behavior near the intake and correlated changes in impingement owing to these variables were examined.

Lorda, E. and S. B. Saila. 1986. A statistical technique for analysis of environmental data containing periodic variance components. Ecological Modeling, Vol. 32, No. 1-3, pp. 59-69.

Abstract: A statistical technique for analyzing data containing periodic variance components when the observations are made at irregular intervals is described. The technique uses a less constrained version of harmonic or periodic regression than that usually employed. The main feature of this method is that a known period is hypothesized, and its component is removed from the data if it is found to be significant. This is in contrast to searching for the presence of unknown periodic components following a classic Fourier analysis. The steps in the analysis are described in detail, and the new method of analysis is applied to the abundance of a marine flatfish captured at the intake of a coastal power plant.

Madenjian, C. P. and D. J. Jude. 1983. Error bounds for estimates of entrained ichthyoplankton. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 40, No. 1, pp. 10-16.

Abstract: Entrainment of fish larvae and eggs was monitored at the J.H. Campbell Plant, eastern Lake Michigan, from 1977 to 1979. A procedure for calculating error bounds for estimated number of fish larvae (or eggs) entrained by the plant for each year of operation, assuming independence among observations, was outlined. A new method for calculating these bounds was devised by adjusting the variance for its non-independent component, using time series analysis. Serial correlation in the data was accounted for by modeling the sequence of entrainment data for a year as a time series.

Marcy, B. C. Jr. and M. D. Dahlberg. 1980. Sampling problems associated with ichthyoplankton field-monitoring studies with emphasis on entrainment. Biological Monitoring of Fish, pp. 233-252.

Abstract: The objective of this account is to present a classification of the basic sampling problems, to define the major causes, to analyze the variables that influence each of the problems, and to provide state-of-the-art literature concerning the monitoring of ichthyoplankton. Entrainment-sampling problems are necessarily emphasized because of the current high level of sampling effort being conducted.

Mattice, J. S. 1987. Compensatory mechanisms in fish populations: literature reviews. Electric Power Research Institute, Palo Alto, Calif.

MacCall, A. D., K. R. Parker, R. Leithiser and W. Jessee. 1983. Power plant impact assessment: a simple fishery production model approach. U.S. Fish and Wildlife Service Fishery Bulletin. Vol. 81, No. 3, pp. 613-619.

McFadden, J. T. 1977. An argument supporting the reality of compensation in fish populations and a plea to let them exercise it. In: Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 3-6, 1977.

Abstract: The concepts in fishery science were developed through experience with stocks subjected to exploitation by man, however, little has been stated about the ability of these stocks to compensate for increased mortality by increased fecundity. This paper outlines the historical development of the concept of compensatory mechanisms within populations and gives examples of compensation in fish populations. This principle is then applied to the assessment of power plant impact on fish populations, with the conclusion that the mortality caused by power plant impingement occurs only once during a 'year-class' life time. Thus a 50% mortality caused by a power plant represents a very much smaller loss to the population of adults than an annually repeated fishing mortality.

Muench, K. 1976. Utility uses a computer to analyze a power plants impact on marine life. Computers and people, Vol. 25, Iss. 12, pp. 25-26.

Murarka, I. P. 1977. A model for predicting fish impingement at cooling water intakes / Argonne, Ill.: Springfield, Va.: Argonne National Laboratory ; available from National Technical Information Service.

Murarka, I. P. and D. J. Bodeau. 1977. Sampling designs and methods for estimating fish-impingement losses at cooling-water intakes. Argonne, Ill.: Argonne National Laboratory.

Murarka, I. P. and D. J. Bodeau. 1977. Software documentation and user's manual for fish-impingement sampling design and estimation method computer programs. Argonne, Ill.: Springfield, Va.: Argonne National Laboratory ; available from National Technical Information Service.

Murarka, I. P., D. J. Bodeau and W. K. Derickson. 1977. Validation and software documentation of the ANL fish-impingement model. Springfield, Va.: The Commission ; Available from National Technical Information Service.

Murarka, I. P., S. A. Spigarelli and D. J. Bodeau. 1978. Statistical comparison and choices of sampling designs for estimating fish impingement at cooling water intakes. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York., Publ. by : EA Communications; Melville, NY (USA)., (Apr. 1978), pp. 267-280.

Abstract: The estimation of fish losses due to impingement is a routine environmental monitoring requirement at cooling-water intakes, but a lack of purpose and design in sampling generally precludes high confidence estimates and collection of data appropriate to the projection of population impacts. Therefore, we have examined several sampling methods and compared the statistical validity and precision of impingement estimates. The stratified systematic random, the systematic random, and

the stratified random sampling schemes offer suitable designs for higher efficiency and improved precision for two models of fish impingement as a time series process. Impingement sampling and present specific recommendations to improve data utility for assessing the losses due to impingement are also discussed.

New York University, Laboratory for Environmental Studies. 1977. The evaluation and description of a power plant condenser tube simulator: a research tool to assess power plant entrainment mortality of aquatic organisms. New York: The Laboratory.

Ogawa, H. and W. J. Mitsch. 1979. Modeling of power plant impacts on fish populations. Environ. Manage., Vol. 3, No. 4, pp. 321-330.

Abstract: A simulation model was developed for assessing the effects of power plant impacts on fish populations. The model was based on biomass changes in a fish population that divided into 4 life stages; eggs, larvae, juveniles, and adults. Power plant impacts on a fish population included entrainment (eggs and larvae) and impingement (juveniles and adults). The model was applied to the *Dorosoma cepedianum* population in Pool 14 of the Mississippi River in Illinois and Iowa. The nearby nuclear power plant, the Quad-Cities Station, is located on the Illinois side. The simulation of the model with the 1976 field data estimates of the power plant entrainment and impingement predicted a 10% potential reduction of the population over 30 years. The simulated reduction of the population with the effects of different river flows showed that the result with the 1976 river flow data gave 1.5 times higher reduction than the results with data of other plant operation years 1972 through 1975. Because the 1976 data recorded low river flow, the 10% reduction quoted above may be high.

Paller, M. H., R. C. Tuckfield and W. M. Starkel. 1995. Statistical methods for detecting ichthyoplankton density patterns that influence entrainment mortality. Journal of freshwater ecology (La Crosse, WI), Vol. 10, No. 3, pp. 231-240.

Abstract: Samples of drifting American shad eggs were collected with 0.5 mm mesh nets at two transects in the Savannah River near industrial water intakes. A teach transect the river was divided horizontally and vertically into four sectors that were sampled at two hour intervals for 24 hour periods to assess horizontal and vertical patterns of egg distribution that could affect vulnerability to entrainment. Egg densities varied by an average factor of 20 over a 24 hour cycle and were consistently highest between2300 and 0300 and lowest between 1300 and 2000. We used two methods to separate spatial from temporal variance, analysis of covariance (ANCOVA) with a polynomial model for time of day as the covariate and a detrending technique in which diel variation was subtracted from each data point. These procedures resulted in substantially more sensitive tests of sector differences as indicated by minimum detectable ratios of sector means that were only half as great as for unadjusted data. Spatial patterns differed between transects but were generally consistent within transects where three to four-fold differences among sector means were common. The actual risk of entrainment was approximately 35-50% lower than if the shad eggs were uniformly distributed, and the risk of entrainment was lower at one intake than at the other. Our results indicate the importance of site specific

assessments of ichthyoplankton distribution near existing or proposed water intakes using statistical designs that permit sensitive resolution of spatial patterns.

Pan, M., Z. Wang, H. Chen and K. Ho. 2000. A model assessing the impacts on fishery resources caused by the cooling system of nuclear power station. Mar. Sci. Bull. Vol. 19, No. 5, pp. 41-46.

Abstract: This paper analyzes the impacts on aquatic organisms in adjacent waters caused by nuclear power station (NPS). Based on calculation of fish entrainment and mortality rate, an assessment model induced from cohort analysis is given. Supposing NPS entrainment to be a fish predator and using cohort analysis, we can calculate natural mortality rate and adult number of certain fish colony if the fishing death rate and catch are known. Then the environmental effects on fishery resources from NPS can be assessed through this model.

Patterson, R. L. 1987. Revised estimates of power plant entrainment of ichthyoplankton in western Lake Erie in 1975-77. Journal of Great Lakes Research, Vol. 13, No. 1, pp. 78-83.

Abstract: Previous estimates of larval production and power plant entrainment, distributed over four power plants, are revised using a lumped parameter method by which power plant mortality is estimated independently of natural mortality. Using the method, mean daily power plant entrainment of four species of ichthyoplankton averaged over three seasons of production (1975-77) ranged from zero to 7.6 percent. These estimates are statistically consistent with earlier estimates made by a more laborious, distributed parameter technique.

Rago, P. J. 1984. Production foregone: An alternative method for assessing the consequences of fish entrainment and impingement losses at power plants and other water intakes. Ecological Modelling, Vol. 24, No. 1-2, pp. 79-111.

Abstract: Losses of fish at power plant and other water intakes have immediate as well as future impacts. Not only is fish biomass removed from the aquatic system, but also the biomass that would have been elaborated by the cohort is not available to other predators. A simple biological production model was modified to allow projections of future impacts associated with current losses of fish and fish larvae. To compute these projections, it is assumed that short-term future responses will be similar to recent survival and growth rates, deducible from analysis of current population structure. The model has several advantages over other approaches. First, a dynamic population model need not be specified. Second, the relative importance of ichthyoplankton versus juvenile and adult fish losses can be compared directly. Third, the ecological effects of future losses can be addressed by considering the predicted size-frequency distributions. Finally, the relative uncertainty of the forecast can be assessed.

Rago, P. J., E. S. Fritz and I. P. Murarka. 1983. Assessing impacts of power plants on fish populations: A general strategy. Environmental Monitoring and Assessment, Vol. 3, No. 2, pp. 185-202.

Abstract: Environmental impact statements are often characterized by extraneous data collection, irrelevant statistical procedures, misapplied models and concomitant ambiguity in conclusions. Impact assessment is difficult but when explicit objectives are not stated and specific tasks are not linked to these objectives, assessment becomes impossible. The authors emphasize a flexible approach that can be adapted to site-specific requirements. The strategy consists of six steps: (1) Conceptualization of the ecosystem, (2) design and execution of pilot studies, (3) refinement of conceptualization, (4) design of a study plan, (5) execution of the study plan and (6) evaluation of impact. Development of a conceptual model leads to specification of testable hypotheses directly linked to the objectives of impact assessment. Deterministic and stochastic simulation modeling can be coupled effectively with traditional statistical methods to reduce the probability of decisions, which impose unnecessary risks on the environment or costs to industry.

Rose, K. A., J. H. Cowan Jr., K. O. Winemiller, R. A. Myers and R. S. O. Hilborn. 2001. Compensatory density dependence in fish populations: importance, controversy, understanding and prognosis. Fish and Fisheries, Vol. 2, No. 4, (Dec. 2001), pp. 293-327.

Abstract: Density-dependent processes such as growth, survival, reproduction and movement are compensatory if their rates change in response to variation in population density (or numbers) such that they result in a slowed population growth rate at high densities and promote a numerical increase of the population at low densities. Compensatory density dependence is important to fisheries management because it operates to offset the losses of individuals. While the concept of compensation is straightforward, it remains one of the most controversial issues in population dynamics. The difficulties arise when going from general concepts to specific populations. Compensation is usually quantified using some combination of spawner-recruit analysis, long-term field monitoring or manipulative studies, and computer modeling. Problems arise because there are limitations to each of these approaches, and these limitations generally originate from the high uncertainty associated with field measurements. We offer a hierarchical approach to predicting and understanding compensation that ranges from the very general, using basic life-history theory, to the highly site-specific, using detailed population models. We analyze a spawner-recruit database to test the predictions about compensation and compensatory reserve that derive from a three-endpoint life-history framework designed for fish. We then summarize field examples of density dependence in specific processes. Selected long-term field monitoring studies, manipulative studies and computer modeling examples are then highlighted that illustrate how density-dependent processes led to compensatory responses at the population level. Some theoretical and empirical advances that offer hope for progress in the future on the compensation issue are discussed. We advocate an approach to compensation that involves process-level understanding of the underlying mechanisms, life-history theory, careful analysis of field data, and matrix and individual-based modelling. There will always be debate if the quantification of compensation does not include some degree of understanding of the underlying mechanisms.

Saunders, W. P., Jr., J. H. Thorp and J. W. Gibbons. 1978. A simple model for assessing the potential loss of adult fish resulting from ichthyoplankton entrainment. In: Energy and environmental stress in aquatic systems., Publ. by Technical Information Center, US Dep. Energy; Oak Ridge, TN (USA), pp. 49-61, DOE Symp. Ser., (No. 48).

Abstract: A mathematical model for estimating potential survival of fish eggs and larvae to reproducing adults is examined in the context of predicting the potential loss from power-station entrainment. It is demonstrated that violating one assumption of the model can result in gross underestimates of potential adult loss. High rates of natural mortality occurring during the egg and larval life stages are considered in relation to the assumption that all exploitation by the power plant occurs instantaneously at spawning or hatching. The sensitivity of potential loss estimates to various time mortality-rate regimenes is examined on the basis of the natural mortality rates observed in young life stages of several species. An alternative model is proposed, and its sensitivity to underlying assumptions is examined. This model is shown to consistently overestimate loss of equivalent adults. The magnitude of the overestimation depends on species-specific conformity of the model assumptions to actual planktonic mortality and first-year survival.

Sharma, R. K. 1977. Survey of fish impingement at power plants in the United States. Argonne, Ill. Springfield, Va.: Argonne National Laboratory ; available from National Technical Information Service.

Sharma, R. K. 1978. Perspectives on fish impingement. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York, Publ. by: EA Communications; Melville, NY (USA), (Apr 1978), pp. 267-280.

Abstract: Data on fish impingement and related parameters are being gathered at a large number of power stations throughout the country at substantial monetary and manpower costs. A national survey of fish impingement at power plants was conducted and much of the resultant information was compiled in a standardized format. This paper examines the objectives of fish impingement studies, monitoring programs, variables affecting fish impingement, siting and design criteria, the state of the art of screening systems, and suggestions for meeting requirements. It also discusses where future emphasis should be placed in fish impingement-related activities.

Shriner, C. R. and J. S. Mattice. 1987. Mechanisms of compensatory response of fish populations: workshop proceedings. Palo Alto, Calif.: Electric Power Research Institute, (Jun 1987).

Small R. D. and B. J. Wilson. 1978. Analyses of serial fish impingement data. Biometrics, Vol. 34, Iss. 3, pp. 535-535.

Stone and Webster Engineering Corporation. 1976. Biological modeling of the effect of entrainment on four selected fish species at the NEPI & 2 site, Charlestown, R.I. Boston: Stone and Webster Engineering Corp.

Summers, J. K. 1989. Simulating the indirect effects of power plant entrainment losses on an estuarine ecosystem. Ecological Modelling, Vol. 49, No. 1-2, pp. 31-47.

Abstract: (1) A simple estuarine trophic dynamics model was constructed to determine the magnitude of the potential losses to major estuarine consumers in the Patuxent River, Maryland, USA, ecosystem due to the power plant-related losses of forage fish. Simulations were completed using two sets of feeding assumptions: feeding proportional to forage abundance, and feeding based on dietary preferences. (2) The model demonstrates that striped bass, bluefish, and weakfish could experience significant losses (> 25%) to overall population production levels if they prefer to prey upon bay anchovy and silversides and entrainment losses to these forage populations is greater than or equal to 70% of juvenile recruitment. (3) The model also shows that indirect predator losses would be expected to be low (< 5%) if the majority of their diets consisted of forage other than bay anchovy and silversides.

Tomlinson, T. and S. F. Atkinson. 1987. Environmental audits: A literature review. Environmental Monitoring and Assessment, Vol. 8, No. 3, pp. 239-261.

Abstract: This paper presents a literature review focused on predictive technique audits, one of the types of audit considered to have the greatest potential role in improving environmental impact assessment practice. The literature review is limited to US literature with the exception of a few UK audits, one undertaken by Tomlinson at the University of Aberdeen. The authors are, however, aware that literature from other countries exists on this subject, for example from Canada and South Africa. In the review, predictive technique audits performed for or by the US Bureau of Land Management, the Electric Power Research Institute, the US Nuclear Regulatory Commission, the US Corps of Engineers, together with the Wisconsin Power Plant Impact Study are described.

Van Winkle, W. and S. W. Christensen. 1979. Incorporation of sublethal effects and indirect mortality in modeling population-level impacts of a stress, with an example involving power-plant entrainment and striped bass. Oak Ridge, Tenn.: Environmental Sciences Division, Oak Ridge National Laboratory.

Vaughan, D. S. and K. D. Kumar. 1981. Detectability and precision of estimates of entrainment mortality of Ichthyoplankton. Washington, D.C., Springfield, Va.: The Commission ; National Technical Information Service.

Vaughan, D. S. and K. D. Kumar. 1982. Entrainment Mortality of Ichthyoplankton: Detectability and Precision of Estimates. Environmental Management, Vol. 6, No. 2, pp. 155-162.

Abstract: (1) The ability to detect entrainment mortality is explored as a function of the sample sizes (numbers of organisms collected) at the intake and discharge sampling stations of a power plant and of the proportion of organisms found alive in the intake samples (intake survival). (2) Minimum detectable entrainment mortality, confidence interval width, and type II error (probability of accepting the null hypothesis of no entrainment mortality when there is mortality) are considered. (3) Increasing sample size

and/or decreasing sampling mortality will decrease the minimum detectable entrainment mortality, confidence interval width, and type II error for a given level of type I error. (4) The results of this study are considered in the context of designing useful monitoring programs for determining the entrainment mortality fraction. (5) Preliminary estimates of intake survival and the entrainment mortality fraction can be used to obtain estimates of the sample size needed for a specified level of confidence interval width or type II error. (6) Final estimates of the intake survival and the entrainment mortality fraction can be used to determine the minimum detectable entrainment mortality and the type II error.

Wainwright, T. C., D. A. Armstrong, P. A. Dinnel, J. M. Orensanz and K. A. McGraw. 1992. Predicting effects of dredging on a crab population: An equivalent adult loss approach. Fishery Bulletin, Vol. 90, No. 1, pp. 171-182.

Abstract: The effect of benthic dredging on coastal fisheries has been of concern for several decades, but little work quantifying direct population impacts has been published. Modeling approaches have been used extensively to assess effects of power plant entrainment on fishery stocks. Several important differences between power plant and dredge operations prevent direct application of these models to dredge problems: Entrainment by dredges is short-term, has a moving intake, and affects all age-classes of the population. We present an equivalent adult loss model of impacts to the Washington coast Dungeness crab *Cancer magister* fishery from dredging of a navigation channel in Grays Harbor, Washington. The model is driven by empirical population data to account for spatial and temporal variation in abundance and age-class structure. Results show that impacts are quite sensitive to the type of dredge used and the season in which dredging occurs. Contrary to initial expectations, the 0 + age-group loss was unimportant relative to losses from older age-classes. Despite many limitations, the model has proven useful for focusing impact assessment work, as a basis for scheduling construction to reduce impacts, and as a basis for scaling mitigation projects.

Wallace, D. N. 1978. Two anomalies of fish larval transport and their importance in environmental assessment. N. Y. Fish Game J., Vol. 25, No. 1, pp. 59-71.

Abstract: Environmental impact assessments for industrial plants using water generally include estimates of ichthyoplankton entrainment. The pattern of transport of fish larvae in water currents determines the proportion of a population, which will pass through the zone of intake influence and the proportion of those passing the intake which will be entrained. Sampling studies revealed 2 anomalies of importance to such estimates: (1) data from field surveys in the Hudson River estuary showed that larvae are not transported in the water mass like solute particles; and (2) data from entrainment monitoring at generating plants on the Great Lakes showed that larval densities in the entrained water are not always the same as those in the surrounding ambient water. Realistic assessment of entrainment impact is both environmentally and economically important, and laboratory observation of the conditions that determine patterns of larval transport would be desirable.

Warsh, K. L. 1975. Hydrological-biological models of the impact of entrainment of spawn of the striped bass (*Morone saxatilis*) in proposed power plants at two areas in the upper Chesapeake Bay.

Zeitoun, Ibrahim H; and others. 1980. Power Plant Water Intake Assessment. Environmental Science and Technology; Vol. 14, No. 4, p398-402, (Apr 1980).

Abstract: In order to adequately assess the impact of power plant cooling-water intake on an aquatic ecosystem, total ecosystem effects must be considered, rather than merely numbers of impinged or entrained organisms.

Zhu, Liangsheng; Wen, W. 1995. A numerical prediction method on effects of the cooling system in a power factory to organisms in water environment. Tropic oceanology/Redai Haiyang. Vol. 14, No. 2, pp. 60-67.

Abstract: The influence of hot, winding and chemical blasts to organisms in the cooling system of a power factory was analyzed in this paper. Then movement mechanism of organisms in water was analyzed, and from these organisms movement differential equation and loss rate control differential equation were deduced, giving the numerical computation method for an organisms loss rate mathematical model. Finally, the blast effects in a certain power factory influencing organisms in ocean environment was predicted by the mathematical model.

## PART III: STUDIES RELATED TO MITIGATION MEASURES OF FISH IMPINGEMENT/ENTRAINMENT BY COOLING-WATER INTAKES

Anon. 1974. Little Fish in a Big Pond Bubble Curtain Keeps Fry Out of Power Plant Intake. Compressed Air, Vol. 79, No. 7, pp. 10-11.

Cada, G. F. and A. T. Szluha. 1979. A biological evaluation of devices used for reducing entrainment and impingement losses at thermal power plants. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Cada, G. F., J. A. Solomon and D. K. Kumar. 1982. Investigation of entrainment stresses using a power plant simulator. Oak Ridge: Oak Ridge National Laboratory.

Chezar, B. 1976. Multifarious power plant water intake structure (MWIS): a design concept to reduce the environmental effects of cooling water intake structures. New York: The Authority.

Cooper, W. E., Jr. 1980. Power plant recirculation and entrainment impact: a solution for constant recirculation and once through mortality rates. Journal of the Alabama Academy of Science. Vol. 51, No. 1, pp. 16-19.

Divanach, P., G. Chevalier and J. M. Lavoue. 1981. (Impact of two detachment systems on the fish impinged on revolving screens.). (Influence of Thermal Discharges on Marine and Estuarine Organisms.). pp. 801-820.

Abstract: The usual detachment systems for fish impinged on the power plants revolving screens, based on water jets, are compared with a new aspiration system. Mortality rates are usually higher for small size fish and for unhealthy fish. The aspiration system tested causes lower mortality rates.

Dorn, P. B. and J. T. Johnson. 1981. Advanced intake technology for power plant cooling water systems: proceedings of the Workshop of Advanced Intake Technology held at the Sheraton-Harbor Island Hotel, San Diego, California, April 22-24. 1981. [Springfield, Va.]: U.S. Fish and Wildlife Service ; available through NTIS.

Dunning, D. J., Q. E. Ross; P. Geoghegan, J. J. Reichle, J. K. Menezes and J. K. Watson. 1992. Alewives avoid high-frequency sound. North American Journal of Fisheries Management, Vol. 12, No. 3, pp. 407-416.

Abstract: The authors studied the response of the alewife *Alosa pseudoharengus* to high-frequency sound to develop an acoustic system for preventing fish from entering power plant intakes. Four groups of alewives were subjected to different frequencies of sounds ranging from 110 to 150 kHz at sound pressure levels (SPLs, given in decibels (dB) in reference to 1 mu Pa) ranging from 125 to 180 dB. Each group of 20 or 25 fish was tested in a cage that was suspended in a flooded rock quarry. During the day, alewives schooled and strongly avoided pulsed tones (500 ms pulses, 1,000 ms apart) of 110 and 125 kHz at or above 175 dB, a continuous tone of 125 kHz at 172 dB, and pulsed broadband sound between 117 and 133 kHz at or above 157 dB. Although alewives

habituated to tones, they avoided pulsed broadband sound at 163 dB more consistently. The more consistent response to the broadband sound was probably due to the range of frequencies in this signal. At night, alewives did not school, did not swim actively, and did not react as strongly to the broadband sound. The diminished avoidance response at night may be due to the absence of schooling and to reduced swimming activity.

Ecological Analysts, Inc. 1979. Evaluation of the effectiveness of a continuously operating fine mesh traveling screen for reducing ichthyoplankton entrainment at the Indian Point Generating Station. New York.

Elarbash, M. M. 1991. Improvements of conventional water intake system. Proceedings of the Twelfth International Symposium on Desalination and Water Re-Use, Malta, April 15-18. 1991. Volume 2: Seawater Reverse Osmosis; Solar Processes; Pretreatment., Vol. 82, No. 1-3. pp. 315-335.

Abstract: Installations that intake water from open water bodies usually obtain the quantities of water required through open channel systems or ducts. Maintenance costs relating to pumps and heat exchangers have been on the rise where water is consumed through open channels including fish, grass and sand. The subject of this paper is the upgrading of the intake head system, a device installed at the upstream end of the pipeline conveying the cooling water to the site onshore. This new invention provides a new intake system that is virtually invisible to suspended matter, fish and seafloor sand. The system was developed by utilizing the continuity equation, which was the main tool for flow calculations. The system also utilizes the natural laws, gravity is the only driving force of the flow.

Elder, J. A., J. W. Icanberry, D. J. Smith, D. G. Henriet and C. E. Steitz. 1979. Assessment of a large-capacity fish pump for sampling ichthyoplankton for power-plant entrainment studies. Rep. CCOFI, Vol. 20, pp. 143-145.

Abstract: The use of pumps to sample plankton from the intakes and outfalls of electric generating plant cooling-water systems is discussed. Conventional pumps have too small a capacity (1mSUP-3) to be useful in sampling ichthyoplankton, therefore a large-capacity pump was utilized in this study. The pump proved more efficient than the net in capturing *Neomysis mercedis*, and was a satisfactory tool for assessing the density of organisms entrained in power plant cooling-water systems.

Electric Power Research Institute. 1989. Field Testing of Behavioral Barriers for Fish Exclusion at Cooling-Water Intake Systems, Ontario Hydro Pickering Nuclear Generating Station, EPRI, Palo Alto, CA, Report GS-6246 (Mar 1989), 140 pp.

Abstract: Depending on site-specific considerations, behavioral barriers such as sound and lights may be more effective, less expensive, and more environmentally suitable for excluding fish from power plant intakes than physical barriers. Specifically, field tests at Ontario Hydro's Pickering station on Lake Ontario indicated that behavioral barriers excluded alewife, an important prey species in the Great Lakes.

Electric Power Research Institute. 1999. Fish Protection at Cooling Water Intakes: Status Report, EPRI, Palo Alto, CA, Report TR-114013. (Dec 1999), 246 pp.

Abstract: The U.S. EPA is developing new regulations to ensure proper implementation of Section 316(b) of the Clean Water Act (CWA), which requires that the location, design, construction, and capacity of cooling-water intake structures (CWIS) reflect the best technology available (BTA) for minimizing adverse environmental impact. This report documents four groups of fish protection technologies that have the potential for CWIS application. Included is information such as how each technology functions, the effectiveness of installations in minimizing aquatic impacts, biological effectiveness for known important species and site conditions, and design and maintenance issues encountered.

Electric Power Research Institute. 2000. Procedural Guideline for Evaluating Alternative Fish Protection Technologies to Meet Section 316(b) Requirements of the Clean Water Act, EPRI, Palo Alto, CA, Report 1000551 (Dec 2000).

Abstract: As part of an effort to develop implementation rules for Section 316(b) of the Clean Water Act (CWA), EPRI commissioned this effort. The goal is to create a technically and biologically defensible screening process for evaluating and identifying alternative fish protection technologies that merit more rigorous evaluation.

Electric Power Research Institute. 2000. Technical Evaluation of the Utility of Intake Approach Velocity as an Indicator of Potential Adverse Environmental Impact under Clean Water Act Section 316(b), EPRI, Palo Alto, CA, Report 1000731, (Dec 2000).

Abstract: This report addresses issues related to causes of fish impingement at cooling-water intake structures (CWISs), specifically the relationship of water velocity, site geometry, fish swimming ability, and environmental conditions. CWIS approach velocity is central to the ongoing U.S. Environmental Protection Agency (EPA) effort to regulate CWISs under Section 316(b) of the Clean Water Act. Energy producers, federal and state resource agencies and regulators, and the public will find this report a valuable reference on impingement issues and appropriate approaches to minimize potential impingement impacts.

Electric Power Research Institute. 2002. CWIS Technologies Workshop: EPRI Research on Cylindrical Wedgewire Screens and Aquatic Filter Barriers, EPRI, Palo Alto, CA, Report 1007006. (Jun 2002).

Abstract: On March 26-27. 2002, EPRI held a workshop on cooling-water intake structure (CWIS) fish protection technology. The goals and objectives were as follows:
o Review EPRI CWIS fish protection technology research
o Obtain input/recommendations and stimulate discussion on EPRI's preliminary results and on their experimental design for 2002+ research
o Provide all with a technical update on the latest CWIS fish protection technology information
Three key research programs were reviewed at the workshop:

o On-going evaluation of cylindrical wedge-wire screens
o A new program evaluating performance (biological and physical) of aquatic filter barriers
o Completed research on bar racks/louvers

Electric Power Research Institute. 2002. Enhancement Strategies for Mitigating Potential Operational Impacts of Cooling Water Intake Structures: Approaches for Enhancing Environmental Resources, EPRI, Palo Alto, CA, Report 1005326 (Jul 2002).

Abstract: This interim report describes environmental enhancement or restoration approaches that may be applicable for mitigating impingement and entrainment impacts associated with cooling-water intake structures (CWISs). These approaches are described with respect to their underlying objectives, implementation and operational requirements, costs, current use by government and the private sector, and advantages and limitations for potentially mitigating CWIS operational impacts.

Fletcher, R. I. 1990. Flow dynamics and fish recovery experiments: Water intake systems. Transactions of the American Fisheries Society, Vol. 19, No. 3, pp. 393-415.

Abstract: Large water-use facilities are often equipped with vertically traveling debris barriers known as Ristroph screens. Although made in a variety of configurations, all such screens are equipped with some manner of fish-catching troughs or rails, and all operate on the principle of direct contact and active removal of impounded fish and debris. The imposed fish mortalities associated with these machines are commonly attributed to the consequences of impingements (to fish being flattened against the screening by the force of the inflowing water), but the laboratory and field experiments reported here imply that in those circumstances where the screens travel continuously and where water speeds are moderate, the major underwater injuries are attributable instead to buffeting of captured fish within the fish troughs proper. A reconfigured machine, including the redesigned fish-catching apparatus, was installed and tested at a nuclear generating station on the Hudson River estuary. In tests similar to those on the unimproved machine, injuries and deaths were reduced from 53 to 9% for striped bass *Morone saxatilis*, from 64 to 14% for white perch *M. american*, from 80 to 17% for Atlantic tomcod *Microgadus tomcod*, and from 47 to 7% for pumpkinseed *Lepomis gibbosus*.

Friedman, R. 1989. Shooing Fish With Sound. Sea Frontiers, Vol. 35, No. 3, pp. 136-141, May-June 1989.

Abstract: Schools of fish routinely clog the water intakes of shoreline power plants and, in unpredictable invasions, schooling anchovies have repeatedly crowded the small harbor of Santa Cruz on the California coast. But new work on shooing fish with underwater sound at the Long Marine Laboratory of the University of California at Santa Cruz, along with contributions from utility company engineers, looks promising. It shows that the schooling behavior of anchovies may provide clues to deterring them from their unwelcome pilgrimages into Santa Cruz Harbor, and to keeping fish other than anchovies away from power plants. Two years ago, Long Marine researchers tested a

seismic "popper" to solve Santa Cruz's crowding problem. The popper, which is basically an air gun that delivers an underwater thump, caused a milling school of anchovies to turn at each blast. Possible explanations as to why the anchovies never seem to habituate to the noise are that the schooling fish would need to stay alert to the signals that they use to navigate as a group and that anchovies may be slow to learn as an adaptation to the selection pressures of their schooling life. The slow habituation of certain fish to sound may also spell success for utility companies. Engineers at Ontario Hydro have found that an array of poppers reduces the number of alewife (*Alosa pseudoharengus*) at the cooling-water intake of Pickering nuclear power station on Lake Ontario. The various fish deterrents, whether they be sound, light, or air bubbles, unfortunately are not reliable for all species all of the time, so the search continues for an appropriate combination.

Fritz, E. S. 1980. Cooling water intake screening devices used to reduce entrainment and impingement. Ann Arbor, Mich.: Washington, D.C.: Fish and Wildlife Service, U.S. Dept. of the Interior. For sale by the Supt. of Docs., U.S. G.P.O.

Goeman, T. J. 1984. Fish survival at a cooling water intake designed to minimize mortality. Progressive Fish-Culturist, Vol. 46, No. 4, pp. 279-281.

Abstract: Fish impingement on water intake screens is one environmental impact associated with cooling systems of electric power generating facilities. Impinged fish can be killed directly or may suffer delayed mortality due to exhaustion, suffocation, or other physical injury. However, not all impinged fish are killed, particularly at newer intakes designed to minimize impingement mortality. Results of previous studies have shown that impingement survival is species specific and that juveniles may exhibit different survival than adults of the same species (Congleton 1974; Haven and Ginn 1977). In the present study, fish survival was monitored at a cooling-water intake designed to minimize impingement-induced mortality. Species-specific responses to impingement were documented for juveniles and adults.

Goeman, T. J. and J. C. Thiel. 1984. A simple weir box for measuring flow rates during entrainment sampling. Progressive Fish-Culturist, Vol. 46, No. 2, pp. 147-148.

Abstract: Entrainment sampling at cooling-water intakes is a vital aspect of evaluating environmental impacts on fish communities. Accurate measurement of the volume sampled is a primary concern if entrainment data is quantified and used to reach meaningful conclusions. In-line flow meters can provide reliable flow data for entrainment studies but costs associated with these instruments are often beyond budget limitations. Flows can also be measured volumetrically using a container of known size. However, this methodology is not considered adequate for some investigations where volumes associated with cooling-water intakes are large and it is necessary to sample a relatively large volume, or vary the sample volume. The authors designed a simple, large capacity weir box for measuring flow during entrainment sampling, resulting in quality data within the budget.

Hadderingh, R. H. and N. V. Kema. 1982. Experimental reduction of fish impingement by artificial illumination at Bergum power station. Int. Rev. Gesamten Hydrobiol., Vol. 67, No. 6, pp. 887-900.

Abstract: Entrapment of juvenile fish at the cooling-water intakes of power stations may lead to considerable fish mortality. At Bergum Power Station, located within the Frisian Lake District, large numbers of juvenile fish are impinged on the cooling-water screens, mainly during the nocturnal hours, due to loss of visual orientation. Artificial illumination of the intake area at the power station was used during the night to reduce the number of fish impinged. Substantial reduction was achieved with ruffe (*Gymnocephalus cernua*) and perch (*Perca fluviatilis*). Effect of the illumination level and phototaxis on the results are discussed. Suggestions to further reduce fish impingement are given.

Hadderingh, R. H. 1979. Fish intake mortality at power stations. The problem and its remedy. Hydrobiol. Bull., Vol. 13, No. 2-3, pp. 83-93.

Abstract: Fish larvae and juveniles are not strong enough to maintain in the water flow occurring at cooling-water intakes of power stations. Therefore, they are drawn into the cooling-water system and show considerable mortality mainly due to mechanical causes. In this paper several measures are discussed which may lead to a reduction of this problem. Special emphasis is laid on site selection in low productive areas, reduction of the volume of cooling water, careful removal and transport from the screens and preventing fish from entering the intake. Illumination of the intake are during night appears to be an effective means in decreasing the large nocturnal fish inflow. It is suggested to modify the current cooling-water standard in order to diminish the intake fish mortality.

Haymes, G. T., P. H. Patrick and L. J. Onisto. 1984. Attraction of fish to mercury vapour light and its application in a generating station forebay. Internationale Revue der Gesamten Hydrobiologie. Vol. 69, No. 6, pp. 867-876.

Hickey, C. R. 1980. Power plant siting and design : a case study of minimal entrainment and impingement impacts at Davis-Besse Nuclear Power Station. Washington, D.C.: Springfield, Va. : Division of Engineering, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission: Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission ; National Technical Information Service.

Hyman, M. A. M. 1975. The effects of two electrical barriers on the impingement of fish at a nuclear power plant. [Kingston]: University of Rhode Island.

Hyman, M. A. M., W. H. Mowbray and S. B. Saila. 1975. The effects of two electrical barriers on the entrainment of fish at a freshwater nuclear power plant. Fisheries and energy production: A symposium.

Abstract: In order to limit the numbers of fish entrained at the Connecticut Yankee Atomic Power Plant (CYAP) at Haddam Neck, Connecticut, it was desirable that a

system be designed to discourage the presence of fish from the immediate environs of the plant intakes. Two such systems are described, both of which statistically reduced the numbers of fish taken. The feasibility of electrical barriers for reducing power plant entrainment in a freshwater environment was demonstrated.

Johnson, L. 1979. A field evaluation of the effect of nighttime flow reduction on entrapment of fish. Seattle, Wash.: Fisheries Research Institute, College of Fisheries, University of Washington.

Jude, D. J. 1982. Adult, Juvenile, and larval fish populations in the vicinity of the James H. Campbell Plant. 1981: with special reference to the effectiveness of wedge-wire intake screens in reducing entrainment and impingement of fish. Ann Arbor, Mich.: Great Lakes Research Division, University of Michigan.

Jude, D. J., P. J. Mansfield and M. Perrone. 1983. Impingement and entrainment of fish and effectiveness of the fish return system at the Monroe Power Plant, western Lake Erie. 1982-1983. Ann Arbor, Mich.: Great Lakes Division, University of Michigan.

Leithiser, R. M., K. F. Ehrlich and A. B. Thum. 1979. Comparison of a high volume pump and conventional plankton nets for collecting fish larvae entrained in power plant cooling systems. J. Fish. Res. Board Can., Vol. 36, No. 1, pp. 81-84.

Abstract: A high volume pump (2.5 mSUP-3 /min capacity at 6 m head) and conventional plankton nets (0.5 and 1.0 m diam) were operated side by side in two tests to evaluate the efficiency of each gear for sampling fish larvae within the intake structure of a coastal power plant. At intake channel current velocities up to 40 cm/s (the maximum tested), the pump in one test caught significantly more fish larvae than the nets. Compared to the pump, both sizes of plankton nets in each test greatly undersampled large larvae (over 5.0 mm total length). These findings suggest that conclusions regarding ichthyoplankton entrainment based on data obtained with conventional plankton nets may be of questionable validity.

Leslie, J. K. 1983. Cooling water flow velocity in relation to collection of entrained larval fish at power plants. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 40, No. 3, pp. 370-373.

Abstract: Velocity of condenser cooling water at numerous sampling sites at some Great Lakes power plants was examined in relation to larval fish entrainment. Current velocity was found to differ significantly in many cases at all depths, for sampling locations spaced 1 m apart in the vertical plane. Extensive use of current meters showed that a simple, pre-sampling study of current velocity at the intake or discharge could improve the accuracy of entrainment estimates.

Lieberman, J. T. and P. H. Muessig. 1978. Evaluation of an air bubbler to mitigate fish impingement at an electric generating plant. Estuaries, Vol. 1, No. 2, pp. 129-132.

Abstract: To determine whether fish impingement at an electric generating plant was significantly reduced during the operation of an air bubbler, impingement monitoring data was subjected to statistical analysis. Daily impingement rates were calculated for

total fish collections and for three impinged species, and associated with water chemistry conditions and air curtain operation during impingement periods. Analysis for each species by season indicated that the air curtain was not an effective fish deterrent.

Matousek, J. A. and A. W. Wells. 1988. Field testing of behavioral barriers for fish exclusion at cooling-water intake systems: Central Hudson Gas & Electric Company, Roseton Generating Station. Electric Power Research Institute, Palo Alto, Calif.

McKinley, R. S., Patrick, P. H. and others. 1989. Field testing of behavioral barriers for fish exclusion at cooling-water intake systems: Ontario Hydro Pickering Nuclear Generating Station. EPRI, Palo Alto, Calif.

Mussalli, Y. G. 1979. Alternative intake designs for reducing entrainment and impingement losses: St. Clair Power Plant, Detroit Edison Company. Boston : Stone & Webster Engineering Corporation.

Mussalli, Y. G., E. P. Taft III and J. Larsen. 1980. Offshore water intakes designed to protect fish. Proc. Am. Soc. Civ. Eng. J. Hydraul. Div., Vol. 106, No. 11, pp. 1885-1901.

Abstract: The engineering design and biological effectiveness of five design concepts for fish protection at offshore intakes are examined. Velocity cap intakes entrap large quantities of fish at some locations and are not effective in preventing the entrainment of fish larvae. Hydrodynamic model studies and tests indicated poor fish diversion and the need for further development. Wedge-wire screen intakes are effective and practical for makeup intakes; however, since proven methods for preventing icing and clogging problems have not been developed, further developmental work is needed for application to once-through cooling intakes. Behavioral barriers, such as an air bubble curtain, a water jet curtain, and hanging chains, have only limited effectiveness in reducing fish entrapment. For makeup water intakes, infiltration systems, such as the radial well intake, are effective, given that a suitable aquifer exists.

Nakato, T. and D. Houser. 1990. Hydraulic model studies of circulating-water ocean-intake velocity caps: Florida Power & Light Company's St. Lucie Power Plant. Iowa City, Iowa: Iowa Institute of Hydraulic Research, The University of Iowa.

Nolen, S. L., J. H. Carroll and J. N. Veenstra. 1988. Development of water release plans for minimizing fish kills below Tulsa District, Corps of Engineers impoundments. Journal of Environmental Systems, Vol. 18, No. 4, pp.353-366.

Abstract: Late summer fish kills comprised primarily of striped bass (*Morone saxatilis*) and associated with high water temperatures, low levels of dissolved oxygen (DO) and fish entrapment occasionally occur in the tail waters of Tulsa District, Corps of Engineers impoundments. In response to these kills, studies were initiated to develop means of using minimal water releases to consistently maintain adequate temperature and dissolved oxygen conditions for fish survival below these projects. Activities included the use of the computer model, SELECT, for the prediction of minimum required releases, followed by field vertification of predicted release characteristics. Results of studies at two lakes are presented here. In both instances, the SELECT model adequately predicted release

characteristics and low level (approximately 0.7 m super (3)/sec),continuous sluice releases were successfully used to prevent fish kills.

Poje, G. V., S. A. Riordan and J. M. O'Connor. 1981. Power plant entrainment simulation utilizing a condenser tube simulator: Final report. Washington, D.C.: Springfield, Va.: The Commission : Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission ; National Technical Information Service.

Ransom, B. H. and T. W. Steig. 1994. Using hydroacoustics to monitor fish at hydropower dams. Lake Reservoir Manage., Vol. 9, No. 1, pp. 163-169.

Abstract: In the USA hundreds of existing hydropower sites have federal operating licenses that expire by the year 2000, and many licenses are being considered for new sites. The mortality to fish passing through hydropower dams has been variously estimated at 2-30%. Many of the power producers applying for licenses in the USA and elsewhere have been required to evaluate the impact their facilities have on fish. Entrainment studies are potentially expensive, labor intensive, and can effect project operations. Estimates of fish entrainment may be required 24 hour/day for up to 12 months, with periodic evaluations of fish survivability through turbine units. Underwater acoustics (sonar) provides one method of obtaining these data that has been accepted by many government fisheries agencies (Federal Energy Regulatory Commission 1987). Fixed-location hydroacoustic techniques have proved effective at documenting and quantify the abundance and behavior of fish passing through hydropower dams, and in reservoirs. In the last 15 years, hundreds of hydroacoustic evaluations of entrainment at hydropower dams have been conducted in the USA.

Ross, Q. E., D. J. Dunning, J. K. Menezes, M. J. Kenna Jr. and G. Tiller. 1996. Reducing impingement of alewives with high-frequency sound at a power plant intake on Lake Ontario. North American Journal of Fisheries Management, Vol. 16, No. 3, pp. 548-559.

Abstract: From April 22 through July 20. 1993, we conducted a follow-up study to confirm that high-frequency broadband sound (122-128 kHz) at a source level (in decibels [dB] in reference to 1 mu Pa) of 190 dB reduced the impingement of alewives *Alosa pseudoharengus* at the James A. FitzPatrick Nuclear Power Plant (JAF), located on Lake Ontario near Oswego, New York. During the first full-scale test in 1991, the sound field covered only the front of the JAF intake. In this second full-scale test, the sound field included the top, sides, and rear of the JAF intake to prevent fish from approaching the intake from those directions when the JAF reactor was shut down and the hot water discharge, located 57 m offshore from the intake, disappeared. Our study also provided the opportunity to evaluate the effectiveness of the deterrent system during a mass die-off of alewives that occurred in Lake Ontario during late spring and early summer in 1993. We used a before-after-control-impact pairs (BACIP) design to test and quantify the effectiveness of the deterrent system. The new sound field reduced the impingement of alewives by 81-84% during a year following an unusually cold winter and should reduce impingement by 87% during most years.

Ross, Q. E., D. J. Dunning, R. Thorne, J. K. Menezes, G. W. Tiller and J. K. Watson. 1993. Response of alewives to high-frequency sound at a power plant intake on Lake Ontario. North American Journal of Fisheries Management, Vol. 13, No. 2, pp. 291-303.

Abstract: From April through June 1991, we tested a full-scale deterrent system for excluding alewives *Alosa pseudoharengus* from the intake of the James A. FitzPatrick Nuclear Power Plant (JAF), near Oswego, New York. This electronic system produced high-frequency broadband sound (122-128 kHz) at a source level (in decibels (dB) in reference to 1 mu Pa) of 190 dB. When the system was on, the density of fish near the JAF intake decreased by as much as 96% and the number of alewives impinged on the intake screens at JAF decreased by as much as 87%. The system was effective during both day and night, and its range was greater than 80 m.

Sager, D. R. 1986. Avoidance behavior of *Morone americana*, *Leiostomus xanthurus* and *Brevoortia tyrannus* to strobe light as a method of impingement mitigation. Thesis/dissertation/manuscript.

Schneeberger, P. J. and D. J. Jude. 1981. Use of fish larva morphometry to predict exclusion capabilities of small-mesh screens at cooling-water intakes. Transactions of the American Fisheries Society, Vol. 110, No. 2, pp. 246-252.

Abstract: A relationship between total lengths and body depths of certain fish larvae was used to predict the effectiveness of small-mesh screens in limiting entrainment of fish larvae at cooling-water intakes. Total length-body depth regressions were linear for eight species (293 larvae) common to Lake Michigan near the J. H. Campbell Power Plant at Port Sheldon, Michigan. Regressions indicated that 35-100% (depending on species) of the fish larvae that had been entrained by the J. H. Campbell Plant in 1978 would have been excluded if 0.5-mm mesh screening had been employed in the plant's cooling-water intake system instead of 9.5-mm bar mesh vertical traveling screens. These calculations do not take into consideration approach velocities of intake water, larva avoidance behavior, or mortality due to impingement on or extrusion through the screens.

Stafford-Glase, M. K. J. Jirka, J. Homa Jr. and P. Kennedy. 1997. Evaluation of strobe lights for deterring fish entrainment at a steam generating electric station. 127th Annual Meeting of the American Fisheries Society, Monterey, CA (USA), pp. 24-28, (Aug 1997). (World Meeting Number 973 5004).

Steen, A. E. and J. R. Schubel. 1986. An application of a strategy to reduce entrainment mortality. Journal of Environmental Management, Vol. 23, No. 3, pp. 215-228.

Abstract: Regulatory agencies have often required power plants to operate at low excess temperatures (Delta Ts) because thermal stresses are believed to be the primary cause of mortality to organisms entrained by the once-through cooling systems of electric generating stations. It has become accepted scientific practice to calculate safe levels of toxics. Procedures to determine the temperature and cooling-water flow characteristics which minimize entrainment mortality were developed and applied. The operating conditions of a power plant on the Potomac River were examined as a case-study to determine whether the plant was operating at, below, or above a maximum tolerate Delta

T. This method may be applied to power plants to determine if entrainment mortality due to thermal effects may occur and what alterations in cooling-water flow would minimize entrainment mortality to selected representative important species.

Taft, E. P. and Y. G. Mussalli. 1978. Fish diversion and transportation system for power plant application. Fisheries, Vol. 3, No. 3, pp. 2-5.

Abstract: An angled, flush-mounted traveling screen has been tested in order to determine its potential for alleviating fish impingement at the cooling-water intakes of electric power plants. Laboratory studies have shown that an angled screen is 100% effective in diverting alewives (*Alosa pseudoharengus*) to a bypass and that these fish can be transported safely through a pipe and jet pump system with low resultant mortality. Such systems are presently incorporated in the design of two new large power plants being constructed on Lake Ontario.

Thomas, G. Lee and L. Johnson. 1980. The Effectiveness of a velocity cap and decreased flow in reducing fish entrapment: final report to Southern California Edison Company, submitted 31 December 1980. Seattle, Wash.: Fisheries Research Institute, University of Washington.

Thorne, R. E., G. L. Thomas, W. C. Acker and L. Johnson. 1979. Two applications of hydroacoustic techniques to the study of fish behavior around coastal power generating stations. Publ. by: WSG; Seattle, WA (USA)., Nov 1979., 33 p., Tech. Rep. Wash. Sea Grant.

Abstract: Acoustic techniques were used to study the behaviour of fish around the cooling-water intake structure of the Southern California Edison Generating Station at Redondo Beach, California. The transducer was positioned on the bottom near the intake and alongside a television camera atop the intake structure. Considerable information was obtained on the diel behaviour of fish and their response to the television camera lights. In the second study the distribution and relative abundance of fish in the water column was investigated prior to, during, and after a shutdown of the San Onofre (Cal.) Nuclear Generating Station. The relative fish abundance changed substantially throughout the study period; it was high in the spring and summer and low in the fall and winter, suggesting the expected seasonal pattern in near shore fish density. However the change in fish density also directly corresponded to the own and resumption of the thermal discharge suggesting that fish may have been attracted to the thermal effluent.

Thorne, R. E. 1980. Application of stationary hydroacoustic systems for studies of fish abundance and behavior. Oceans '80. An international forum on ocean engineering in the '80s., Publ. by: IEEE; New York, NY (USA), pp. 381-385., Oceans '80.

Abstract: This study reports on two applications of stationary hydroacoustic systems: one at a coastal power plant intake in Southern California, and the second under the ice near Prudhoe Bay, Alaska. Several advantages of stationary systems were apparent, including more detailed information on fish behavior, capability for detection closer to boundaries, and better signal to noise characteristics.

Turnpenny, A. W. H., K. P. Thatcher, R. Wood and P. H. Loeffelman. 1993. Experiments on the use of sound as a fish deterrent. Fawley Aquatic Research Labs. Ltd. (England) Rept. No.: ETSUT0400171REP, 79 pp.

Abstract: (1) This report describes a series of experimental studies into the potential use of acoustic stimuli to deter fish from water intakes at thermal and hydroelectric power stations. (2) The aim was to enlarge the range of candidate signals for testing, and to apply these in more rigorous laboratory trials and to a wider range of estuarine and marine fish species than was possible in previous initial preliminary studies. (3) The trials were also required to investigate the degree to which fish might become habituated to the sound signals, consequently reducing their effectiveness. (4) The species of fish which were of interest in this study were the Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), the shads (*Alosa fallax*, *A. alosa*), the European eel (*Anguilla anguilla*), bass (*Dicentrarchus labrax*), herring (*Clupea harengus*), whiting (*Merlangius merlangus*) and cod (*Gadus morhua*). (5) All of these species are considered to be of conservation and/or commercial importance in Britain today and are potentially vulnerable to capture by nuclear, fossil-fuelled and tidal generating stations. (6) Based on the effectiveness of the signals observed in these trials, a properly developed and sited acoustic fish deterrent system is expected to reduce fish impingement significantly at water intakes. (7) Field trials at an estuarine power station are recommended.

Weisberg, S. B. 1984. The effects of screen slot size, screen diameter, and through-slot velocity on entrainment of estuarine ichthyoplankton through wedge-wire screens. Annapolis, Md.: Maryland. Dept. of Natural Resources, Power Plant Siting Program.

Weisberg, S. B., W. H. Burton, F. Jacobs and E. A. Ross. 1987. Reductions in ichthyoplankton entrainment with fine-mesh, wedge-wire screens. North American Journal of Fisheries Management, Vol. 7, No. 3, pp. 386-393.

Abstract: The exclusion efficiency of cylindrical wedge-wire screens was investigated at the Chalk Point Steam Electric Station in Aquasco, Maryland, by measuring entrainment of larval bay anchovies *Anchoa mitchilli* and naked gobies *Gobiosoma bosci* through screens with slot sizes of 1, 2, and 3 mm and through an unscreened intake. The degree of exclusion by the screens increased with fish size. Fish less than 5 mm long were not excluded by any of the screens. In contrast, more than 80% of larger ichthyoplankton were excluded by all screens. Virtually no ichthyoplankton larger than 10 mm were entrained through the 1-mm screen even when fish of this size were abundant and were entrained through the unscreened intake. The results suggest that entrainment through water intake structures can be successfully reduced by wedge-wire screens if the larval fish at risk exceed 5 mm in length.

Wiancko, P. M. 1981. Environmental Design and Operation of Nanticoke Thermal Generating Station. Journal of Great Lakes Research, Vol. 7, No. 2, pp. 96-104.

Abstract: The 4,000 MW fossil-fueled Nanticoke Thermal Generating Station (TGS) located in Long Point Bay was commissioned in 1978. Ontario Hydro became involved with the Nanticoke Environmental Committee (NEC) through its involvement with various government agencies in the design and licencing approvals for the station. At full

load, up to 150 m super (3) multiplied by s) super(-)1o)f cooling water is used by the station, similar to 60% for condenser cooling and 40% for discharge tempering. Only 1% is used for plant services. All chemical-laden wastes, fly ash and bottom ash, treatment plant wastes, coal pile drainage, and sewage are pumped to a 76 ha lagoon for maximum recirculation with continuous drainage to the lake at a rate of up to 0.4 m super(3) multiplied by s super(-1). This is after a lagoon retention time of approximately 40 days. All oil storage sites at Nanticoke TGS are dyked with further plans for their upgrading. Oil spill contingency plans are also being improved to contain accidental spills before they reach the lake. To minimize blowing coal dust, the station has adopted specific wetting, shaping, and reclaiming procedures for operation of the coal site. The station monitors all water processing and waste systems, air quality (SO sub(2)), fugitive coal dust, fish impingement, and seasonal stack impingement of birds. Some results are presented.

Wu, L-J., K-T., Lee, S-R. Leu and C-H. Liao. 1989. Estimation of abundance of carangids near the water intake of nuclear power plant I by dual-beam hydroacoustic methods. Journal of the Fisheries Society of Taiwan [J. FISH. SOC. TAIWAN.], Vol. 16, No. 3, pp. 175-188.

Abstract: (1) The water pumping of the Nuclear Plant I has resulted in mechanical injuries of certain fish species as they swim near the influx filter net. (2) The present study takes the fish school of carangids to measure their target strength by means of dual-beam acoustic approach. (3) This effort duly coordinated with fishing experiment to verify the feasibility of employing in-situ target strength as a scaling factor. (4) Furthermore, in a joint effort with underwater optical method to determine the actual fish density, one looks into the reliability of estimation of carangids swimming to the cooling-water intake using echo integration technique.

Zeitoun, I. H., J. A. Gulvas and D. B. Roarabaugh. 1981. Effectiveness of fine mesh cylindrical wedge-wire screens in reducing entrainment of Lake Michigan Ichthyoplankton. Can. J. Fish. Aquat. Sci., Vol. 38, No. 1, pp. 120-124.

Abstract: Samples of ichthyoplankton entrained through 2.0-mm and 9.5-mm-slot opening cylindrical wedge-wire screens and through an open pipe (control) were collected in June, July, and August 1979, 1067 m off the southeast shore of Lake Michigan at a depth of 10.7 m. Screens were designed for a flow rate of 1.9 mSUP-3 /min at 15.2 cm/s through slot velocity. Ambient composition and density of ichthyoplankton were determined by net tows. *Osmerus mordax*, *Alosa pseudoharengus*, and *Perca flavescens* larvae were common in both entrainment and tow collections. Eggs were found almost exclusively in entrainment collections. Ambient larval fish densities were about 11 times greater than those found in entrainment collections. Total entrainments through either screen and the open pipe were not statistically significant. Larval avoidance and, to a lesser extent, screen exclusion were responsible for the low entrainment. The authors estimated that about 90% of native fish larvae at the site avoided pumping.

Zweiacker, P. J., J. R. Gaw, E. Green and C. Adams. 1977. Evaluation of an air-bubble curtain to reduce impingement at an electric generating station. Proc., Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies, No. 31, pp.343-356.

Abstract: A biological testing program was conducted during 1974-75 to determine the efficiency of an air-bubble curtain in reducing fish impingement at Arkansas Nuclear-One Unit 1, on Dardanelle Reservoir, AR. Air curtain operation did not effectively deter fish from entering the intake canal or substantially reduce impingement. Seasonal variations in species composition and length-frequency distribution of impinged fish were independent of air curtain operation. There was a significant inverse correlation between water temperature and impingement levels during fall 1974 and spring 1975. Highest impingement rates occurred during late fall, winter, and early spring, regardless of air curtain status. Impinged individuals were predominantly young-of-the-year fish, especially *Dorosoma petenense* and *D. cepedianum*, assumed to be thermally stressed by low (<15.5 C) water temperatures.

## PART IV: OTHER RELEVANT STUDIES RELATED TO FISH IMPINGEMENT/ENTRAINMENT BY COOLING-WATER INTAKES

Anon. 1978. An analysis of factors influencing the impingement of threadfin shad at power plants in the southeastern United States. In: Fourth national workshop on entrainment and impingement, 5 December 1977, Chicago, Illinois. Sponsored by: Ecological Analysts, Inc., Melville, New York, Nat. Workshop Entrain. Impinge., Publ. by : EA Communications; Melville, NY (USA)., Apr 1978., p. 245-255.

Abstract: Data on intake design and location, plant operating procedures, water quality, numbers of fish impinged, and sampling procedures were analyzed for 27 fossil-fueled and 5 nuclear power plants located on inland waters in the southeastern United States. Small clupeids (<9 cm), especially threadfin shad (*Dorosoma pretenense*), comprised the majority of the fish impinged at these facilities. The parameter that was correlated most highly with shad impingement was water temperature. Maximum impingement rates occurred during the winter when intake temperatures dropped below 10 C. Analyses of differences in impingement rates between plants failed to adequately demonstrate that the magnitude of impingement at a particular plant was the result of any site-specific characteristics associated with intake design or location. High approach velocities at the traveling screens did not necessarily result in high levels of impingement. Results obtained from inter-unit comparisons at several plants indicate that unit and screen differences do exist, but it is unclear from existing data whether or not such inter-unit differences determine the magnitude of impingement losses or merely affect the distribution of impinged fish at a given intake structure. Recommendations for monitoring fish impingement are presented.

Anon. 1975. (Influence of water intakes of two nuclear Stations (St. Laurent and Chinon) on fish other than salmon, and general conclusions: first observations (spring 1975)). CSP, Region piscicole 'Auvergne-Limousin', Clermont-Ferrand (France). 14 p.

Abstract: The average numbers of fishes (other than salmon) rejected daily by the drums of the nuclear power stations of St-Laurent (counts made between 29/4 and 22/5) and Chinon (1/5 to 10/5) were estimated respectively to be {approx} = 550 and {approx} = 2500 fishes. 86% of these fishes at St-Laurent and 99% at Chinon were small-sized Cyprinidae (length < 10 cm), with a high proportion of roach and bleak. The larger fishes (length > 10 cm) were also mainly Cyprinidae (roach, beaked carp and bream) but some carnivores (pike perch, perch), Salmonidae (trout) and others (lampreys, eels, cat-fishes) were also noted. The proportion of fishes rejected in a healthy state was estimated as 15% at St-Laurent, < 5% at Chinon. Some spp. (pike perch, trout) seemed less fragile than others (roach, beaked carp, bream, etc). Nearly 3000 fishes were destroyed each day, i.e., a biomass of 24 kg/24hr distributed almost equally between the 2 stations. Certain reservations must be made concerning the precision and generalization of these results: some of the fishes rejected were probably dead already before entering the stations; the number of small fishes (difficult to separate from the plant debris) was underestimated; there was a lack of observations at other times of the yr. Some general conclusions are

drawn: the destruction of young salmon is not very great; but this is already a threatened sp; the destruction of other spp. is significantly higher but the piscicole value of the river should not be greatly affected. Various safety measures could be taken: creation of an outlet for the direct return to the river from the downstream portion of the water-intake canal; modifications of the external structure of the drums (to facilitate the evacuation of the fishes).

Anon. 1976. 316(b) report, Widows Creek Steam Plant: effects of the Widows Creek Steam Plant cooling water intake on the fish populations of Guntersville Reservoir. [Knoxville, Tenn.]: Tennessee Valley Authority.

Attrill, M. J. and R. M. Thomas. 1996. Long-term distribution patterns of mobile estuarine invertebrates (Ctenophora, Cnidaria, Crustacea: Decapoda) in relation to hydrological parameters. Marine Ecology Progress Series, Vol. 143, No. 1-3, pp. 25-36.

Abstract: Between 1977 and 1992, semi-quantitative samples of macro-invertebrates were taken at fortnightly intervals from the Thames Estuary (UK) utilizing the cooling-water intake screens of West Thurrock power station. Samples were taken for 4 h over low water, the abundances of invertebrates recorded in 30 min subsamples and related to water volume filtered. Abundances of the major estuarine species have therefore been recorded every 2 wk for a 16 yr period, together with physico-chemical parameters such as temperature, salinity and freshwater flow. Annual cycles of distribution were apparent for several species. *Carcinus maenas* exhibited a regular annual cycle, with a peak in autumn followed by a decrease in numbers over winter, relating to seasonal temperature patterns. Conversely, abundance of *Crangon crangon* was consistently lowest in summer, responding to seasonal changes in salinity, whilst *Liocarcinus holsatus*, *Aurelia aurita* and *Pleurobrachia pileus* were only present in summer samples, with *P. pileus* often in vast numbers (>100,000 per 500 million l). The estuarine prawn *Palaemon longirostris* showed no obvious sustained annual pattern, but evidence for a longer cycle of distribution was apparent. During 1989-1992 severe droughts in southeast England severely disrupted annual salinity patterns and coincided with a large increase in the Chinese mitten crab *Eriocheir sinensis* population. This included the first synchronized migration of adults in the UK. Settlement of young crabs during low-flow periods is suggested as an explanation for this population increase.

Bauml, G. A. 1996. Evaluating fish impingement and entrainment at the Comanche Peak Steam Electric Station Thesis/dissertation/manuscript.

Beard, L. M., D. J. Bruggink, J. P. Buchanan, R. A. Buckingham and D. L. Dycus. 1985. Aquatic environmental conditions in Chickamauga Reservoir during operation of Sequoyah Nuclear Plant: Fifth annual report.

Abstract: TVA is required by its National Pollutant Discharge Elimination System (NPDES) Permit for Sequoyah Nuclear Plant (SQN) to conduct and report annually on operational non-radiological monitoring to evaluate potential effects of SQN on Chickamauga Reservoir. Because few changes were identified through 1984, the following changes were recommended in June 1985: (1) terminate studies on benthic macro-invertebrates, mollusk bioaccumulation, fish impingement, fish gill netting, fish

creel surveys, and water quality at the plant intake and discharge; (2) continue studies on plankton and larval fish with specific changes; and (3) continue cove rotenone studies without change. These recommendations were instituted in July 1985 following approval from the Environmental Protection Agency (EPA). This report evaluates 1985 results for the continued portions and, briefly, for the discontinued portions conducted prior to EPA's approval. Evaluation of water quality data showed that during low flows SQN altered the distribution of DO in the water column at and downstream of the diffusers. Studies to define the extent and duration of the DO alteration will be conducted during spring and summer when SQN resumes operation (DBO).

Benda, R. S., M. John and J. Gulvas. 1975. Comparison of fish impingement at the Palisades nuclear power plant for once-through and closed-cycle cooling. Proc. Indiana Acad. Sci., 85, 155-160.

Abstract: Two studies of fish impingement were conducted at the Palisades Nuclear Power Plant. The first (May 16, 1972 to October 25, 1973) during once-through cooling and a second (March 10, 1974 to March 29, 1975) during closed-cycle cooling using mechanical draft cooling towers. The Palisades facility, which has an ultimate electrical output up to 821 megawatts, began operations in early 1972. The cooling-water intake is submerged 1006m offshore at a minimum depth of about 7.6 m. The heated discharge enters the lake directly at the shoreline. The total flow rate was about 30686 l/s during once-through cooling and 4644.5 l/s during closed cycle cooling. From May 16, 1972 to October 25, 1973 daily records showed a total of 651,712 fish weighing 19,842.2 kilograms were impinged on the traveling screens. Of these totals, alewife (*Alosa pseudoharengus*), slimy sculpin (*Cottus cognathus*), spottail shiner (*Notropis hudsonius*), and perch (*Perca flavescens*) made up 58.6, 27.5, 7.2, and 4.4%, respectively, of the total number. Coregonoids and salmonids, and smelt, *Osmerus mordax* made up 0.2 and 1.0% of the total respectively. The fish appeared seasonally on the screens with none of the 37 recorded species being collected regularly. In addition, 4,768 crayfish, (*Oronectes propinquis*) were counted, mostly during late spring and early summer. Results from the March 10, 1974 to March 29, 1975 study showed 2724 individuals weighing 25 kg were impinged during 111 screen counts which represented 31.3% of the total number of hours the screens were operated. Slimy sculpin and alewife made up 85.8 and 11.4% respectively of the total, with seven other species comprising the additional 2.8%. Extrapolation of the data (based upon weekly screen counts) showed that potentially 7,488 fish weighing 68 kg could have been impinged. An additional 8,096 crayfish were impinged and extrapolation show that potentially 10,218 could have been impinged. The change from once-through cooling to closed cycle cooling resulted in a significant decrease in the total number, weight, and number of fish species impinged at the Palisades Plant resulting in a reduction of biomass removed from the inshore area Lake Michigan near South Haven.

Best, C. D. and D. W. Morgan. 1977. Factors affecting ichthyoplankton entrainment in the Michigan City generating station condenser cooling water system. Proc. Indiana Acad. Sci., Vol. 87, pp. 170-171.

Abstract: Analysis of ichthyoplankton entrainment data collected at the NIPSCO Michigan City generating station indicates a correlation between temperature changes and density of alewife, carp, and spottail shiner larvae. The plankton sampling program was conducted from 3 May to 23 August. 1976, with the first occurrence of the 3 species found on 27 May when average temperatures of intake and discharge waters were 15.4 C and 20.0 C respectively. Mean larval densities varied directly with temperature from 12 June to 14 July. The first major increase in the density of carp, alewife and spottail shiner larvae occurred on 16 June when average intake temperature was 21.1 C and average discharge temperature was 27.2 C. The mean density of all larvae dropped sharply on July 26 when water temperatures averaged 24.1 C at the intake crib and 31.7 C in the discharge plume. Thereafter, a mean density of larvae varied inversely with discharge temperature changes, with relatively fewer larvae being found when temperatures were above 29.0 C. No significant correlation was found between larval density and plant flow, rainfall, or barometric pressure.

Bimber, D. L. 1984. Field distribution and entrainment of fish larvae and eggs at the Donald C. Cook Nuclear Power Plant, southeastern Lake Michigan: 1973-1979. Ann Arbor (Mich.): University of Michigan, Great Lakes Research Division.

Boreman, J., D. H. Arner and others. 1977-1980. Topical briefs, fish and wildlife resources and electric power generation. [Ann Arbor, Mich.] : Power Plant Project, Office of Biological Services, Fish and Wildlife Service, U.S. Dept. of the Interior.

Carter, K. L. and J. P. Reader. 2000. Patterns of drift and power station entrainment of 0+ fish in the River Trent, England. Fisheries Management & Ecology 7, No. 5, pp. 447-464.

Abstract: Entrainment of 0+ riverine fish (mostly pelagic cyprinids) by a power station intake, and down-river drift over a nearby weir, followed the same pattern, occurring throughout the year and being greatest during the night in the first weeks of life (i. e. in summer), reaching a peak shortly after dusk. Entrainment and drift of benthic species, and of fish older than 0+, were negligible. Mortality following entrainment was 100%. Impingement of fish on the intake screens was negligible, probably because individuals larger than the screen mesh were able to escape the intake current. The species composition and length-frequencies of the drifting fish, but not their overall abundance, showed some variation with distance from the river margin. It is argued that the fish vulnerable to entrainment are those 0+ individuals which are dispersing in the river by drifting.

Chen, C. W. 1981. Power plant intake systems database. C.W. Chen; prepared for Electric Power Research Institute. Palo Alto, CA: Electric Power Research Institute.

Chioffi, N. and D. J. Jude. 1984. Impingement losses at the D.C. Cook Nuclear Plant during 1975-1979: with a discussion of factors responsible and relationships to field catches. Ann Arbor, Mich.: Great Lakes Research Division, University of Michigan.

Cooper, C. L., J. J. Mizera and C. E. Herdendorf. 1981. Power Plant Entrainment of Larval Fishes in the Western and Central Basins of Lake Erie. Twenty-Fourth Conference on

Great Lakes Research and Annual Meeting of the International Association for Great Lakes Research, Columbus, OH, 28-30 Apr 81. (World Meeting Number 812 5010).

Dunstall, T. G. 1985. Effects of entrainment on phytoplankton primary production at four thermal electric generating stations on the Laurentian Great Lakes. Internationale Revue der gesamten Hydrobiologie (Berlin), Vol. 70, No. 2, pp. 247-257.

Abstract: Primary production was used to measure the response of phytoplankton to entrainment in once-through cooling water at thermal electric generating stations. Ambient lake water temperatures ranged from 1.0 to 20.5 degree C. The maximum discharge temperature was 32.0 degree C. There was no chlorination of cooling water at the stations studied. On a few occasions, primary production was stimulated following station passage by discharge temperatures which were approximately 10 degree C above ambient lake water temperatures of 4.5 to 8.5 degree C. Entrainment was considered to have minimal impact on phytoplankton productivity in large open water bodies such as the Great Lakes.

Electric Power Research Institute. 1982. Ecological Investigations at Power Plant Cooling Lakes, Reservoirs, and Ponds: An Annotated Bibliography, EPRI, Palo Alto, CA, Report EA-1874, (Jun 1982), 176 pp.

Abstract: This report contains citations and abstracts of published and unpublished reports on ecological investigations at power plant cooling lakes, reservoirs, and ponds. Data are provided on facility location (region and state), operator, unit name, capacity, status, year on-line, fuel, water body, and cooling system.

Evans, M. S. and L. E. Flath. 1984. Intakes as sampling locations for investigating long-term trends in zooplankton populations. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 41, No. 10, pp. 1513-1518.

Abstract: The authors present data demonstrating the representativeness of a power plant intake as a sampling location for investigating long-term trends in zooplankton populations. The intake (Donald C. Cook Nuclear Plant) and the inshore region (southeastern Lake Michigan) were sampled within a matter of days on 54 occasions between April 1975 and November 1981. Intake population estimates were significantly correlated with inshore region population estimates for all 26 zooplankton taxa categories analyzed. Differences in abundances in intake and inshore region samples were not significant for most euplanktonic taxa. The plant apparently entrained water and micro-crustaceans from the sediment-water interface. However, because vertically hauled plankton nets do not effectively sample the lower1 m of the water column, intake sampling may provide a more accurate representation of near shore region copepod and cladoceran community structure than traditionally employed methods for inshore region sampling.

Foster, J. R. and T. J. Wheaton. 1981. Losses of juvenile and adult fishes at the Nanticoke Thermal Generating Station due to entrapment, impingement, and entrainment. Journal of Great Lakes Research, Vol. 7, No. 2, pp. 162-170.

Abstract: From April 1976 to June 1977, juvenile and adult fish mortality at the power plant was determined by examining the numbers, sizes, species, and health of fish entrapped by the western intake, impinged on the traveling screens, and entrained through the tempering pumps. These data indicate that the cooling-water system of the plant entraps many valuable commercial and sport species, virtually all of which are subsequently killed. Mortality of entrapped fish was primarily due to entrainment through the tempering pumps, with only a small fraction due to impingement on the traveling screens. Mortality was highest among transient schooling species. The contribution of the eastern and western intakes to fish entrapment and mortality appeared to differ significantly.

Ginn, T. C. W. T. Waller and G. J. Lauer. 1974. The effects of power plant condenser cooling water entrainment on the amphipod, *Gammarus sp*. Water Research. Vol. 8, No. 1, pp. 931.

Abstract: The abundant Hudson River amphipod *Gammarus sp* was examined for viability before and during entrainment in the Indian Point cooling-water system. The mean per cent survival of *Gammarus sp* sampled during {Delta}T's of 7.1-8.3{degree}C and ambient temps of24.9-26.0{degree}C was 98.5 and 97.4% for the 2 intake stations and 90.1 and 96.8% for the discharge canal stations D-1 and D-2respectively. A statistically significant ({alpha} = 0.05) difference was detected between the survival of *Gammarus sp* at the intake stations and discharge station D-1, located near the upper end of the discharge canal. Entrained *Gammarus sp* experience increased initial and latent mortalities during periods of condenser chlorination. Comparison of the abundances of entrained *Gammarus sp* during day and night sampling periods reveals a significantly higher occurrence during darkness. Temp bioassays indicate that the thermal tolerance of *Gammarus sp* is dependent on exposure time and ambient temp. the temp resulting in a 50%mortality of *Gammarus sp* for 30 min exposure times, increased{approx} 11{degree}C as ambient temps increased from 2.5 to25.8{degree}C. Consequently, *Gammarus sp* was capable of surviving {Delta} T's of greater magnitude as the ambient temp to which they were acclimated decreased. Temp bioassays indicated that *Gammarussp* should be able to tolerate all projected time-temp exposure combinations encountered during entrainment through the cooling-water system.

Greenland, D. C. and A. E. Thomas. 1972. Swimming speed of fall chinook salmon (*Oncorhynchus tshawytscha*) fry. Transactions of the American Fisheries Society, Vol. 101, No. 4, pp. 696-700.

Abstract: Tests to determine the swimming ability of fall Chinook salmon fry were conducted in a stamina tunnel located at the Salmon Cultural Lab., Longview, Wash. Fish were subjected to water velocities of 0.6, 0.7, 0.8 and 0.9 ft/sec for periods of 3, 6, and 9 min. The number of fish impinged on a screen placed across the downstream end of the stamina tunnel was noted for each test. The number offish free of the screen and still swimming at the end of the test period was used as the measure of swimming ability. The smallest group tested, fry 33.0 to 34.9 mm in length, had visible yolk sacs. 98% of these fish were capable of coping with velocities of0.6 ft /sec for at least 3 min. Only 88% and 72% of these small fish could cope with increased velocities of 0.7 and 0.8

ft/sec. Larger fry performed better; however, a slump in performance in fish 37.0 to 38.9 mm in length was noted. Changes of 0.05 ft/sec caused measurable changes in swimming performance, and the number of fish impinged increased with exposure time.

Hadderingh, R. H. 1978. Mortality of Young Fish in the Cooling Water System of Bergum Power Station. Congress in Denmark 1977. Internationale Vereinigung fur theoretische und angewandte Limnologie/Proceedings. International Association of Theoretical and Applie Limnology/Travaux. Association internationale de Limnologie theorique e appliquee (Stuttgart), Vol. 20, No. 3, pp. 1827-1832.

Abstract: Substantial numbers of larvae and juveniles are drawn into the cooling system of the Bergum power station. The highest numbers, up to 10 million per 24 hours, are found in May. This study shows that smelt is the most vulnerable species: entrainment mortality 75%, impingement mortality 95%. For the Percidae (pike-perch, perch) the respective mortalities are 34 and 65%. Most entrainment mortalities as shown by Marcy (1975) in a survey, are higher (90-100%) probably because of other circumstances. To diminish mortality due to entrainment and impingement can be achieved by decreasing the amount of cooling water. Besides, investigations will be carried out to keep the fish (juveniles) away from the intake by electrical barriers or by diverting the fish to a bypass.

Hadderingh, R. H., G. H. F. M. van-Aerssen, L. Groeneveld, H. A. Jenner and J. W. van-der-Stoep. 1983. Fish impingement at power stations situated along the Rivers Rhine and Meuse in the Netherlands. Hydrobiological-Bulletin. Vol. 17, No. 2, pp. 129-141.

Harmon, P. L. 1981. Entrainment and impingement of fish at five electric generating stations on the Delaware River. Millersville, Pa.: State College.

Johnson, M. G. 1984. Great lakes fisheries and environmental issues. Advances in Environmental Science and Technology, Vol. 16 pp. 1-8.

Abstract: Stresses on aquatic communities attributable to human activities include toxic metals and organic compounds, limnological changes due to excessive nutrient enrichment, acid rain, mortalities at water intakes by impingement and entrainment, losses of natural littoral habitat, depreciation of streams and bays in many places, pressures from exotic species, and overexploitation. In the face of effects from these stresses, combined with variability due to natural factors, it becomes extremely difficult to attain tolerable fluctuations in quantity and quality of fish yields. Instability does not favor public and private investment in the resource, and, to add insult to injury, funds available of management of the stocks and fisheries may be diverted to programs aimed at understanding and dealing with stresses imposed by the activities of other water users, often on a too-short-term, fire-fighting basis. Fisheries agencies cannot avoid dealing with these issues, not only because we must try to understand major stresses, whatever their origin, but also because we have the expertise and he conviction to protect and, if necessary, to rehabilitate aquatic communities. However, it is important to control how we shall perform this task, which is a central concern of this book.

Jordan, R. A. and C. E. Sutton. 1984. Oligohaline benthic invertebrate communities at two Chesapeake Bay power plants. Estuaries, Vol. 7, No. 3, pp. 192-212.

Abstract: Benthic invertebrate populations at the Surry power plant on James River, Virginia and the C.P. Crane power plant on Saltpeter Creek, Maryland exhibited large spatial and temporal variations. At C.P. Crane, where the cooling water is pumped between two tidal creeks, populations in the receiving creek exhibited five response patterns: 1) mitigation of a winter dieoff (*Rangia cuneata*, a brackish water clam), 2) acceleration of growth or development (*R. cuneata*; *Scolecolepides viridis*, a polychaete; *Leptocheirus plumulosus*, an amphipod; Tubificidae; and *Coelotanypus sp*., a dipteran), 3) importation of larvae from the source water creek (*S. viridis* and *Coelotanypus sp*.), 4) extension of creek-dwelling species into the adjacent river (*Coelotanypus sp*. and other dipterans), and 5) increased severity of late summer population depressions (*S. viridis* and *L. plumulosus*). At Surry, where the cooling water is taken from the downriver side of a peninsula and discharged on the upriver side, there was no confined creek system at the discharge, and effects were less pronounced.

Jude, D. J., P. J. Mansfield, S. F. DeBoe and F. J. Tesar. 1986. Spatial distribution of entrained fish larvae in a power plant discharge canal. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 43, No. 5, pp. 1070-1074.

Abstract: Larval fish were sampled with plankton nets during June and July at 1-, 3-, and 5-m depths at three stations in the 6-m-deep discharge canal of the Monroe electricity-generating plant on western Lake Erie. Of nine species, gizzard shad (*Dorosoma cepedianum*) accounted for 96% of all larval fish collected in June and, along with freshwater drum (*Aplodinotus grunniens*), 78% of those taken in July. Densities of fish larvae at the three depths and at two of the three stations sampled, were not significantly different. Mean densities of gizzard shad and total fish larvae in June were significantly higher at one station. Fluctuating and significantly lower velocity at that station, causing the flowmeter not to turn while the net was still filtering water, was suspected of causing inflated densities. Generally sizes of larvae were not stratified by depth or station; differences that were found were small.

Kelso, J. R. M. and G. S. Milburn. 1979. Entrainment and Impingement of Fish by Power Plants in the Great Lakes Which Use the Once-Through Cooling Process. J. Great Lakes Res. Vol. 5, No. 2, pp. 182-194.

Leslie, J. K., R. Kozopas and W. H. Hyatt. 1979. Considerations of entrainment of larval fish by a St. Clair River, Ontario, power station. Tech. Rep. Fish. Mar. Serv. (Can.), (Jun 1979), No. 868, 30 p.

Abstract: Larval fish entrainment by the Lambton generating station was estimated at 22.5 x 10SUP-6 for the ten week sampling period (April 10-June 21. 1978). Smelt (*Osmerus mordax*) comprised approximately 96% of the total. Two larval species previously unreported in the river, fourhorn sculpin (*Myoxocephalus quadricornis*) and silver chub (*Hybopsis storeriana)* together formed 3%, while seven species formed the

remaining 1%. The total absence of walleye (*Stizostedion vitreum vitreum*) larvae in all samples generated increased concern for its abundance, if not survival, in the area.

Liston, C. R., D. C. Brazo and others. 1981. Assessment of larval, juvenile, and adult fish entrainment losses at the Ludington pumped storage power plant on Lake Michigan: 1980 annual report. Ludington Project, Vol. 1: East Lansing, Mich.: Dept. of Fisheries and Wildlife, Michigan State University.

Lohner, T. 2001. Cooling water intake system impacts on Ohio River fish. 131st American Fisheries Society Annual Meeting, Phoenix, AZ (USA). 19-23 Aug 2001. (World Meeting Number 000 5724).

Madenjian, C. P., D. J. Jude and F. J. Tesar. 1986. Intervention analysis of power plant impact on fish populations. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 43, No. 4, pp. 819-829.

Abstract: Alewife (*Alosa pseudoharengus*) and yellow perch (*Perca flavescens*) abundances, estimated from monthly gillnet and trawl catches at two transects, were monitored before (1973-74) and during (1975-82) operation of the D.C. Cook Nuclear Power Plant, southeastern Lake Michigan. Intervention analysis, a technique, which accounts for auto-correlated observations, and analysis of variance (ANOVA) were applied to the monitoring data to assess any plant impact beginning in 1975. Both analyses disclosed no significant power plant impacts except for gillnetted yellow perch adults. The ANOVA indicated a significant decrease in abundance at the plant-discharge transect relative to the reference transect as plant operation began, which established a plant effect; intervention analysis showed no change. When April and May catches (months of low abundance) were deleted, this plant effect was insignificant.

Madenjian, C. P., D. J. Jude and F. J. Tesar. 1986. Intervention analysis of power plant impact on fish populations. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 43, No. 4, pp. 819-829.

Abstract: Alewife (*Alosa pseudoharengus*) and yellow perch (*Perca flavescens*) abundances, estimated from monthly gillnet and trawl catches at two transects, were monitored before (1973-74) and during (1975-82) operation of the D.C. Cook Nuclear Power Plant, southeastern Lake Michigan. Intervention analysis, a technique which accounts for auto-correlated observations, and analysis of variance (ANOVA) were applied to the monitoring data to assess any plant impact beginning in 1975. Both analyses disclosed no significant power plant impacts except for gillnetted yellow perch adults. The ANOVA indicated a significant decrease in abundance at the plant-discharge transect relative to the reference transect as plant operation began, which established a plant effect; intervention analysis showed no change. Monte Carlo simulation showed that as the first-order autoregressive coefficient increased positively, type 1 error of the ANOVA F-test increased. However, ANOVA was more powerful than intervention analysis when a first-order autoregressive component was included.

Mansfield, P. J. and D. J. Jude. 1986. Alewife (Alosa pseudoharengus) survival during the first growth season in southeastern Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences, Vol. 43, No. 7, pp. 1318-1326.

Abstract: Alewife (*Alosa pseudoharengus*) survival from newly hatched larvae to fall young-of-the-year (YOY) was calculated using data collected in southeastern Lake Michigan, June-November 1974-82. Alewife YOY density (number per 1000m super(3)) was estimated from trawl catches. Larval alewife densities, derived from plankton net samples at trawling stations and from power plant entrainment samples, were averaged each year for length intervals which represented yolk-sac and post-yolk-sac larvae. Survival (ratios of YOY to larval alewife densities) varied considerably among years, but mean survival over all years from yolk-sac larvae to YOY was 1% calculated from either field-larvae or entrained-larvae data. Mean survival from post-yolk-sac larvae to YOY was higher, 2.2-4.6%. Differences in survival among years may be due to timing of sampling, distribution of larvae and YOY, or actual survival differences, perhaps related to predator abundance.

Marcy, C. Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. J. Fish. Res. Board Can. Vol. 30, no. 8, pp. 1195-1200.

Abstract: Most of the young fish of 9 spp. that were entrained in the condenser cooling-water system of the Connecticut Yankee nuclear power plant were dead by the time they reached the lower end of the plant's 1.83-km (1.14 mile) long discharge canal. Sampling during June and July, when 95 per cent of the non screenable fish were abundant near the plant's intake, showed that approx. 80 per cent of the mortality in the canal was caused by mechanical damage and 20 per cent was attributed to heat shock and prolonged exposure to temps elevated greater than 28 degrees C. There was no measurable mortality due to the injection of sodium hypochlorite into the system as a biocide. The number of non screenable living fish entrained at the intake averaged about 4 per cent (range, 1.7-5.8 per cent) of those passing by the plant under conditions of unidirectional net tidal flow.

Masilamoni, J. G., K. S. Jesudoss, K. Nandakumar, K. K. Satpathy, K. V. K. Nair and J. Azariah. 2000. Jellyfish ingress: A threat to the smooth operation of coastal power plants. Current Science, Vol. 79, No. 5, pp. 567-569.

Abstract: Coastal areas are often preferred for setting up power stations due to the easy availability of sea water for condenser cooling. In such coastal power stations, there are instances of plant shutdown due to excessive accumulation of fouling debris inside the cooling circuits. Recently, there have been a few instances, when jellyfish in large numbers entered the seawater cooling system of the Madras Atomic Power Station (MAPS) at Kalpakkam, Tamil Nadu, India causing plant shutdown. While moderate ingress of jellyfish leads to a reduction in the plant efficiency, large arrivals may even lead to forced shut down of a power plant. The present study deals with the ingress of jellyfish in MAPS cooling-water system and its impact on the power plant operation.

McFarlane, R. W., R. A. Frietsche and R. D. Miracle. 1979. Community structure and differential impingement of Savannah River fishes. Proc., Annu. Conf., Southeast. Assoc. Fish Wildl. Agencies, Vol. 33, pp. 628-638.

Abstract: The fish communities of the middle Savannah River and 2 cooling-water intake canals connected to the river had equal species richness and were equally diverse. However, the relative abundance of functionally similar species groups differed between the localities. Sunfishes were more dominant in the canal communities. Suckers contributed 55% of the biomass in all 3 communities. Impingement was very low and spread over 32 species. Three species of clupeids comprised 32% of the total number of fish impinged. The impingement of a number of species was disproportionate to their relative abundance in the intake canals.

McKinley, R. S., R. A. Hester, B. Sim and S. M. Legrow. 1986. Assessment of ichthyoplankton entrainment at Bruce A generating station. IAGLR-86 Program. International Association For Great Lakes Research 29th Conference, May 26-29. 1986, p. 43.

Abstract: The objective of this study was to assess ichthyoplankton entrainment at Bruce A Nuclear Generating Station from April to September. 1985. Total number of eggs entrained was 55.4 x 10 super(6), with the peak occurring in April. Total larval entrainment was 59.6 x 10 super(6), with an initial peak in June and a lesser peak in August. Burbot (*Lota lota*), rainbow smelt (*Osmerus mordax*), alewife (*Alosa pseudoharengus*) and deepwater sculpin (*Yoxocephalus thompsoni*) accounted for 88 and 98% respectively of the eggs and larvae collected in the intake-forebay. Most of the smelt and alewife larvae were classified as dead prior to entrainment. Larval mortality attributable to intake passage was greater for all species than passage through the station.

McLean, R. B. 1980. Threadfin shad impingement: effect of cold stress : report to the Nuclear Regulatory Commission for period October 1. 1976, to September 30. 1978. Washington, D.C.: Springfield, Va.: The Commission : Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission ; National Technical Information Service.

McLean, R. B., J. S. Griffith and M. V. McGee. 1985. Threadfin shad, *Dorosoma petenense* (Guenther), mortality: Causes and ecological implications in a South-eastern United States reservoir. Journal of Fish Biology, Vol. 27, No. 1, pp. 1-12.

Abstract: Cold stress was identified as an important factor influencing both reservoir-wide mortality and impingement of threadfin shad, *D. petenense* during the period October 1976 to April 1977 in Watts Bar Reservoir, Tennessee. Relative numbers and size frequency of impinged threadfin shad were similar to the relative numbers and size frequency of shad preyed upon by sauger, *Stizostedion canadense*, and skipjack herring, *Alosa chrysochloris*. This relationship implies that the factor mainly responsible for impingement, low temperature, also influences prey vulnerability. Threadfin shad made up 99% of the combined diet of sauger and skipjack herring from November until the threadfin shad disappeared in January.

McLean, R. B., P. T. Singley and D. Lodge. 1981. Threadfin shad impingement, population response: Final report to the Nuclear Regulatory Commission for period October 1. 1978 to September 30. 1980. Washington, D.C.: Springfield, Va.: The Commission: Available from GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission; National Technical Regulatory Commission.

Noguchi, L. S. 1985. Field distribution and entrainment of fish larvae and eggs at the Donald C. Cook Nuclear Power Plant, Southeastern Lake Michigan. 1980-1982. Ann Arbor, Mich.: Great Lakes Research Division, University of Michigan.

Page, H. M., J. E. Dugan, D. S. Dugan, J. B. Richards and D. M. Hubbard. 1999. Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. Marine Ecology Progress Series, (Aug 1999), Vol. 185, pp. 47-57.

Abstract: The distribution, abundance, and population characteristics of large, highly mobile crab species (*Cancer antennarius, C.anthonyi, C. productus, Loxorhynchus grandis*) differed in relation to an offshore oil platform in the Santa Barbara Channel, California, USA. Only *C. antennarius* individuals recruited onto the platform, primarily into the attached community of *Mytilus galloprovincialis* and *M. californianus* at depths of <12 to 15 m. The higher CPUE (catch per unit effort) of *C. antennarius* beneath the platform, compared with nearby soft bottom stations, suggested that this species remained primarily in the vicinity of the platform. Although *C. anthonyi* did not recruit at the platform, adult female *C. anthonyi* were attracted to the platform from surrounding habitat. The higher CPUE of female *C. anthonyi* beneaththe platform, compared with soft bottom stations, suggested that habitat selection is related to reproduction in this species. *C. productus* and *Loxorhynchus grandis* were present in low numbers at all benthic stations. The distribution and abundance of these crab species fit into 3 of 4 hypothesized scenarios that described different combinations of recruitment, distribution and abundance of mobile species around oil platforms: (1)`recruitment/emigration', a platform provides recruitment habitat and individuals that recruit to the platform emigrate at some point to the surrounding environment, (2) `recruitment/resident', a platform provides recruitment habitat, but individuals remain in the vicinity of the structure (*C. antennarius*), (3) `attraction', individuals that recruited elsewhere are attracted to and aggregate at a platform (*C. anthonyi*), and (4) `visitor', individuals that recruited elsewhere occur temporarily at the platform without aggregation (*C. productus, L. grandis*). Our results, in the context of these scenarios, illustrate the need to consider the responses of individual species to artificial structures.

Page, T. L., D. A. Neitzel and R. H. Gray. 1978. Comparative fish impingement at two adjacent intakes on the mid-Columbia River. In: Fourth national workshop on entrainment and impingement, Chicago, Illinois, December 5, 1977. Sponsored by: Ecological Analysts, Inc., Melville, New York, Publ. by : EA Communications; Melville, NY (USA), (Apr 1978), pp. 267-280.

Abstract: Fish impingement on the mid-Columbia River is a concern only from April through June each year and is limited to a few species. From May through June 1977 a

comparison of fish impingement was made at two water intake facilities located about 276 m apart on the Columbia River at River Mile 380. The intakes each have a capacity of over 25 cu m/sec, are similarly designed, and have comparable water intake velocities. Collections from the traveling screens at 100-N yielded a total of 89 chinook fry. During the same period 766 chinook fry were collected at the Hanford Generating Project (HGP). Extensive studies indicate that this sample represents an estimated impingement of 2,695 chinook fry, 97% of which survived. Impingement for 10 other species of fish was similar at both intakes, except that HGP impinged about twice as many yellow perch fry as did 100-N (2642 versus 1296). Several hypothesis are offered to explain the differences in impingement between the intakes. These include subtle differences in forebay configuration, curtain wall location, and possible differences in fish behavioral responses to the two facilities.

Paller, M. 1992. Ichthyoplankton entrainment study at the SRS Savannah River water intakes for Westinghouse Savannah River Company. Final report. Tech. Rep. Westinghouse Savannah River Co., 405 pp.

Abstract: Cooling water for L and K Reactors and makeup water for Par Pond is pumped from the Savannah River at the 1G, 3G, and 5G pump houses. Ichthyoplankton (drifting fish larvae and eggs) from the river are entrained into the reactor cooling systems with the river water and passed through the reactor's heat exchangers where temperatures may reach 70(degrees)C during full power operation. Ichthyoplankton mortality under such conditions is assumed to be 100 percent. The number of ichthyoplankton entrained into the cooling system depends on a variety of variables, including time of year, density and distribution of ichthyoplankton in the river, discharge levels in the river, and the volume of water withdrawn by the pumps. Entrainment at the 1 G pump house, which is immediately downstream from the confluence of Upper Three Runs Creek and the Savannah River, is also influenced by discharge rates and ichthyoplankton densities in Upper Three Runs Creek. Because of the anticipated restart of several SRS reactors and the growing concern surrounding striped bass and American shad stocks in the Savannah River, the Department of Energy requested that the Environmental Sciences Section (ESS) of the Savannah River Laboratory sample ichthyoplankton at the SRS Savannah River intakes. Dams & Moore, Inc., under a contract with Westinghouse Savannah River Company performed the sampling and data analysis for the ESS.

Paller, M., J. O'Hara, V. Osteen, W. Specht and J. Kania. 1984. Annual report on the Savannah River Aquatic Ecology Program, September 1982-August 1983. Vol. 1. ECS-SR-8, 275 pp.

Abstract: This document reports on the Savannah River Aquatic Ecology Program for the period September 1982 through August 1983. Volume 1 covers fisheries studies including ichthyoplankton, entrainment, impingement, diurnal studies, adult fish studies and special quality assurance tests and quality assurance programs.

Patterson, R. L. and K. D. Smith. 1982. Impact of power plant entrainment of ichthyoplankton on juvenile recruitment of four fishes in western Lake Erie in 1975-77. Journal of Great Lakes Research, Vol. 8, No. 3, pp. 558-569.

Abstract: The effect of power plant entrainment on juvenile recruitment of four species of ichthyoplankton in western Lake Erie was investigated. Of the four species studied -- gizzard shad (*Dorosoma cepedianum)*, white bass (*Morone chrysops*), walleye (*Stizostedion vitreum*) and freshwater drum (*Aplodinotus grunniens*) -- it was found that the effect on walleye year class strength is minimal while the effect on gizzard shad recruitment may possibly be significant in terms of overall impact on the community ecology of the western basin. This aspect of the impact of power plant entrainment should be further investigated. It was estimated that total juvenile recruitment of these four species would increase by 742 individuals per acre if all power plant entrainment were eliminated.

Patterson, R. L. 1979. Production, mortality, and power plant entrainment of larval yellow perch in western Lake Erie. Publ. by: EPA; Duluth, MN (USA), (Aug 1979). 199 p., Ecol. Res. Series U. S. Environ. Protect. Agency.

Abstract: The impacts of the Monroe Power Plant upon the yellow perch population of western Lake Erie caused by entrainment and impingement of larvae and older fishes in the plant's open cycle cooling system in 1975-1976 are assessed. Estimates of total numbers of perch larvae entrained, total perch production, the natural mortality rate of perch, and the percentage of perch production that was entrained by the Monroe Power Plant were obtained. Impingement estimates were obtained from data supplied by the power plant. The estimates consider only effects that occur in the same year in which entrainment and impingement occurs. Impacts may occur in subsequent years including a depression of fish stocks and reduced yields to the fishery. Losses to the standing stocks and fisheries were estimated using a method which falls into a category known as the 'equivalent-adult' type which provided estimates of the long-run annual depression of yellow perch standing stocks and the yellow perch fisheries. A numerical model was developed which incorporated several population parameters including entrainment and impingement losses and natural mortality rates for larvae, young-of-year and juveniles, and fishing mortality rates.

Porak, W. and J. A. Tranquilli. 1981. Impingement and entrainment of fishes at Kincaid Generating Station. The Lake Sangchris Study: Case History Of An Illinois Cooling Lake, Ill. Nat. Hist. Surv. Bull., Vol. 32, No. 4, pp. 631-655.

Abstract: From December 1976 through March 1977, 94.16 percent of the estimated total impingement occurred. Gizzard shad (83.38 percent) and yellow bass (14.26 percent) accounted for 97.46 percent of the estimated 158,853 fish impinged on the screens. Small fishes were the most vulnerable to impingement; 93.8 percent of all the fish collected were less than 200 mm in total length. Only 218 fish eggs were collected during entrainment sampling, accounting for a relatively low total estimate of 2.2 million eggs lost during the spawning season. Gizzard shad (85.61 percent). *Morone* spp. (4.03 percent), and *Lepomis* spp. (0.66 percent) accounted for most of the larval fish entrained. During 1976 impingement and entrainment at Kincaid Generating Station's cooling-water intake system caused only relatively minor reductions in numbers of a few overabundant and/or undesirable species, and consequently was found to have no adverse impact on either the individual populations of those species or the sport fishery.

Potter, W. A. 1979. Rancho Seco Nuclear Generating Station: 1979 Fish impingement and entrainment programs.

Potter, W. 1978. Assessment of the effects of impingement and entrainment on the fish community of the New River, Virginia. Thesis/dissertation/manuscript.

Rajagopal, S., K. V. K. Nair and J. Azariah. 1989. Some observations on the problem of jelly fish ingress in a power station cooling system at Kalpakkam, east coast of India. Mahasagar. Dona Paula [Mahasagar.], Vol. 22, No. 4, pp. 151-158.

Abstract: The seasonal distribution and abundance of jelly fishes in the coastal waters of Kalpakkam (Tamil Nadu, east coast of India) in the context of their ingress into the cooling system of a power plant was studied. Three species of jelly fishes *Dactylometra quinquicirrha*, *Crambionella stuhlmanni* and *Chiropsalmus buitendijki*, were found in such abundance as to cause blockage of the cooling-water intake screens. The seasonal variation in the incidence of the jelly fishes clearly showed that the periods of maxima and minima were different for each species. During the study period (February 1988 to April 1989) three maxima were noted - May, July and October. On any given single day, maximum quantity of jelly fishes collected from the travelling screens was 29 tonnes (21 July 1988). The data are discussed with respect to: (1) qualitative and quantitative variations in the ingress; (2) operational problems associated with ingress; and (3) possible approaches to combat the problem.

Reutter, J. M. 1981. Fish impingement at the Davis-Besse nuclear power station during 1980: environmental technical specifications, sec. 3.1.2.a.6, fish impingement. Columbus, Ohio: Ohio State University, Center for Lake Erie Area Research,

Reutter, J. M. 1981. Fish egg and larvae entrainment at the Davis-Besse nuclear power station during 1980: environmental technical specifications Sec. 3.1.2.a.5 fish egg and larvae entrainment. Columbus, Ohio: Ohio State University, Center for Lake Erie Area Research.

Reutter, J. M., C. E. Herdendorf and G. W. Sturm. 1978. Impingement and entrainment studies at the Acme and Bay Shore Power Stations, Toledo Edison Company : 316 (B) program, Task I : Appendix C, entrainment results . Columbus, Ohio: Center for Lake Erie Area Research, Ohio State University.

Rodgers, D. W. 1995. Comparison of impinged and open-water alewives at Pickering Nuclear Generating Station, Lake Ontario. North American Journal of Fisheries Management, Vol. 15, No. 1, pp. 152-155.

Abstract: I compared alewives Alosa pseudoharengus impinged at Pickering Nuclear Generating Station on the northwestern shore of Lake Ontario with alewives seined along the lakeshore. The characteristics assessed included morphological measurements, counts of the principal fin rays, allelic frequencies for more than twenty-five protein-coding loci, and pathological and parasitological condition. In general, impinged alewives were similar to alewives in the open water. Impingement did not appear to select unhealthy fish, and the allelic frequencies of impinged alewives did not differ significantly (P >

0.05) from open-water fish. However, impinged alewives had significantly ($P < 0.05$) lower body weights and liver weights, at an equivalent length, than open-water fish. The observed differences were suggestive of exhaustion of the impinged alewives, but the causes of exhaustion and impingement have yet to be resolved.

Savitz, J., L. G. Bardygula-Nonn, R. A. Nonn and G. Wojtowicz. 1998. Impingement and entrainment of fishes within a high volume-low velocity deep-water intake system on Lake Michigan. J. Freshwat. Ecol. Vol. 13, no. 2, pp. 165-169.

Abstract: The extent of fish entrainment and impingement was determined for a low velocity-high volume Lake Michigan water intake system where the entrance of the intake system occurred in deep waters. There was no evidence of any fish entrainment probably because of the location of the entrance to the water intake system. Fish impingement was also low and comparable to the lowest impingement found for power plant intakes. The number of impinged fish was 93 fishes for 58 sampling dates from April 23 to November 13. Of the 93 fishes, 61 were alewives, 11 were yellow perch, and the remainder included black crappie, black bullhead, bloater, bluegill, emerald shiner, johnny darter, pumpkinseed, slimy sculpin, and spotfin shiner. The impact of this intake system on the fish community was insignificant, since the estimated total of impinged fishes during the operating season of the intake was 280.

Sawyko, P. M. S. 1999. Review of twenty-five years of fish impingement at Rochester gas and electric's Ginna nuclear power station. 42nd Conference of the International Association for Great Lakes Research, Cleveland, OH (USA), pp. 24-28, (May 1999). (World Meeting Number 992 5051).

Sazaki, M., W. Heubach and J. E. Skinner. 1972. Some preliminary results on the swimming ability and impingement tolerance of young-of-the-year steelhead trout, king salmon and striped bass.

Scott-Wasilk, J., R. Kunshek, D. T. Michaud, A. E. Gaulke and J. H. Balletto. 1981. A Comment on the Paper by John R.M. Kelso and Gary S. Milburn: "Entrainment and Impingement of Fish by Power Plants in the Great Lakes Which Use the Once-Through Cooling Process" (J. Great Lakes Res. 5: 182-194. 1979). Journal of Great Lakes Research, Vol. 7, No. 4, pp. 491-497.

Abstract: Assessment of entrainment and impingement impact of the 89 steam-electric generating stations on Great Lakes fish stocks reported by Kelso and Milburn (1979) is evaluated. Despite the large number of fish impinged at these stations, impingement losses typically constituted less than 1% of the standing stocks of fish in the lakes. Similarly, entrainment losses also represented a small fraction of total larvae in the lakes. Therefore, power plants alone probably have minimal impact on the Great Lakes sport and commercial fisheries and no detectable impact on fish populations. Despite Kelso and Milburn's assertion to the contrary, future fish losses from proposed generating capacity expansion may be less, due to improvements in cooling-water intake design.

Smith, K. A. and M. L. Brown. 2002. Seasonal Composition and Abundance of Ichthyoplankton Entrained through Big Bend Dam, South Dakota. Journal of Freshwater Ecology; Vol 17; Part 2; pp. 199-208.

Snyderman, M. 1989. California Nuke Plant Blamed for 'Marine Goop' That's KillingOcean; Sea Life. Underwater USA, Vol. 6, No. 2, pp. 29, June 1989.

Abstract: The San Onofre Nuclear Generating Station on the Pacific shore of California is again surrounded by controversy. Patches of thick sludge and sticky silt, referred to as "marine goop" by environmentalists, are smothering sea life along the ocean floor. The Coastal Commission advisory panel investigated this "marine goop" and concluded that the plant's cooling system was responsible for creating this material which has tripled in size since its discovery just south of the outfall pipes 3 yr. ago. The scientific panel has reported that the goop has turned the once prolific bottom of the sea into a barren oceanic wasteland. The nuclear plant takes in two million gallons of Pacific Ocean water every minute to help cool its reactors before discharging the water back into the sea. Upon being discharged, the cooling-water's temperature has been raised to an average temperature of 19-22 degrees higher than the water in the ocean. Water temperatures in Southern California typically range between 57-68 degrees over the course of an average year. Experts agree that this elevated water temperature plays a major role in the health and survival of many sea creatures. The generally accepted theory is that the "marine goop" is what is formed when the hot water plume comes out of the San Onofre plant. This plume has small particles of dirt and the consensus of opinion is that the turbulence caused by the plume combines small organisms within organic material, giving it cohesiveness. This cohesive goop then settles to the bottom, creating a suffocating layer of sludge. Surprisingly, some forms of plankton, which were originally expected to perish in the goop, are actually thriving, but populations of several mid-water species are being seriously diminished in an area that was once a thriving kelp forest community.

Sukackas, V. 1993. Morphological variability (power plant impact.). Ecosystem Of The Water-Cooling Reservoir of Ignalina Nuclear Power-Stationat The Initial Stage of its Operation., Sostoyanie Ehkosistemy Vodoemaokhladitelya Ignalinskoj Ash V Nachal'nyj Period Ee Ehkspluataciji.,Academia, Vilnius (Lithuania), p. 156, Therm. Power Generationenviron./Teploehnerg. Okruzhayushchaya Sreda., Vol. 10, No. 2.

Abstract: Variability of 23 morphological parameters of roach (*Rutilus rutilus*) in warmer and colder water zones of Ignalina nuclear power plant (Lithuania)was investigated. Fishes of 27-35 cm long were taken into consideration. The programme of generalized estimation of properties was applied. According to stable features reliable differences between those two zones of roach were not observed.

Thoernqvist, S., E. Neuman, A. Jacobsson and O. Sandstroem. 1998. Biological monitoring at Ringhals nuclear power plant 1988-1996. Fiskeriverk. Rapp. No. 1, 20 pp.

Abstract: Losses of fish eggs and larvae were estimated at the cooling-water intake screens of Ringhals nuclear power plant (Sweden), and the impact in the effluent area was studied by standardized fyke net fishing. The possible large-scale influence on fish

stocks was investigated by analyzing catch data in the commercial fishery. The main conclusions are: 1.The recruitment of some stationary littoral fish species has likely been damaged by the losses of eggs and larvae at the intake screens. 2. Results from the fyke net fishing indicates that the recruitment damage in these species has resulted in a negative development of adult abundance, although other cooling-water impacts in the effluent area may have contributed to this effect. 3. The presence of different species in the effluent area is strongly influenced by their temperature preference. Attraction as well as avoidance has been documented. 4. Climate variations, either natural or caused by human activities, add to the impacts of cooling water. Avoidance reactions have been stronger during the warm summers of the 1990's. 5. Commercial catch data do not suggest any regional impacts on the fish stocks related to the intake of cooling water and the heated discharge.

Thurber, N. J. and J. D. Jude. 1985. Impingement losses at the D.C. Cook Nuclear Power Plant during 1975-1982 with a discussion of factors responsible and possible impact on local populations. University-of-Michigan-Great-Lakes-and-Marine-Waters-Center-Special-Report-of-the-Great-Lakes-Research-Division. 1985, No. 115, pp. 1-70 & A1-A88.

Wahtola, C. H., R. W. Clubb and G. F. Boronow. 1977. The Lake-wide effects of impingement and entrainment on the Lake Michigan fish populations. Milwaukee, WI: CDM/Limnetics Environmental Consultants.

Winchell, F. C., E. P. Taft, J. K. Downing, J. Mattice and C. W. Sullivan. 1993. Review of fish entrainment and mortality studies. Waterpower'93 - International Conference on Hydropower, Nashville, TN (USA), 10-13 Aug 1993. (World Meeting Number 933 5006).

Wright, D. A., V. S. Kennedy, W. H. Roosenburg, M. Castagna and J. A. Mihursky. 1983. Temperature tolerance of embryos and larvae of five bivalve species under simulated power plant entrainment conditions: A synthesis. Marine Biology, Vol. 77, No. 3, pp. 271-278.

Abstract: (1) Thermal tolerance studies on three larval stages of five species of bivalve are compared: *Crassostrea virginica, Mulinia lateralis, Argopecten irradians, Mercenaria mercenaria* and *Spisula solidissima*. (2) Experiments were designed to simulate possible larval entrainment in the cooling systems of power plants. (3) For all species, larval mortality generally increased with increasing exposure temperature and with increased time exposure at any one temperature. (4) In some species (*M. mercenaria* and *A. irradians*) a cold-shock was also apparent (i.e. increased mortality at temperatures below those at which the larvae were spawned). (5) In the case of *A. irradians*, this effect was more noticeable at the trochophore stage than at the other two stages, although for all species investigated, there was a general trend of decreased thermal sensitivity with increasing age. (6) Despite some interspecies variability from temperature to temperature and from stage to stage, *S. solidissima* was the most sensitive species and *A. irradians* was intermediate in thermal tolerance between this and the other three species.

Wright, D. A., W. H. Roosenburg and M. Castagna. 1984. Thermal tolerance in embryos and larvae of the bay scallop *Argopecten irradians* under simulated power plant entrainment conditions. Marine ecology progress series, Vol. 14, No. 2-3, pp. 269-273.

Abstract: Thermal tolerance was tested in cleavage stages, trochophores and straight hinge larvae of the bay scallop *Argopecten irradians*. Experiments were designed to simulate larval entrainment in power plant cooling systems. In general, higher mortalities were associated with higher temperatures and with longer time exposure at any one temperature. However, there was some evidence of cold shock in trochophore and straight hinge larvae, with elevated mortalities occurring at temperatures lower than the spawning temperature. There was a trend towards increased thermal tolerance is older larvae, although in general *A. irradians* showed the greatest sensitivity to thermal shock of the estuarine bivalves so far tested in our laboratory.

Wyman, R. L. and R. S. Dischel. 1984. Factors influencing impingement of fish by Lake Ontario power plants. Journal of Great Lakes Research, Vol. 10, No. 4, pp. 348-357.

Abstract: Fish impinged by two Lake Ontario power plants were examined to determine the causal factors. Fish were near shore because they resided there, migrated there to spawn or forage, or because the water mass in which they resided moved near shore. Once near shore, fish abundance in impingement collections was correlated with demersal with demersal of pelagic behavior. Periodic increases in diversity and abundance of impinged fish corresponded with times of upwelling and thermocline scillations. These data suggest that some species were segregated along temperature gradients and were impinged when the thermocline passed near the intake. *Alosa pseudoharengus* and *Osmerus mordax* were apparently attracted to water currents entering the intake. *Morone americana, Morone chrysops, Dorosoma cepedianum*, and *Perca flavescens* were not influenced by changes in flow rate, suggesting that their impingement was proportional to their density in nearshore water. *Micropterus dolomieui* avoided the intake at higher flow rates in part due to rheotactic behavior.

Zhidovinov, V. I., N. G. Degtyareva, E. K. Lebedeva and V. Sil'va. 1986. Effect of water intake and discharge tubes on young fish entrainment into pumping house. (Protection and Development Of Fishery Resources in the Caspian Sea.)., Okhrana I Vosproizvodstvo Rybnykh Zapasov Bassejna Kaspijskogo Morya., pp. 82-89.

Abstract: Young white bream and bream (*Abramis*) are most easily entrained into water intake tubes whereas roach and herrings are less susceptible. As weirs and water intake contribute towards formation of young fish concentrations it is recommended that intake and discharge tube should be located down the river with respect to the streamline fin.

Zimin, V. L., O. V. Bodrov and I. N. Ryabov. 1992. Analysis of the influence of the Leningrad nuclear power plant water intakes on the ichthyofauna of the cooling water body. Vopr. Ikhtiol./J. Ichthyol., Vol. 32, No. 3, pp. 182-186.

Abstract: The paper presents results of the Fourier analysis of data on the numbers, biomass and linear sizes of fish (by species) collected from the water cleaning screens of the water intakes. High mortalities of commercial fish species necessitate installation of special fish protection devices on the intakes.

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Environmental Protection Agency. 1977. Guidance for evaluating the adverse impact of cooling water intake structures on the aquatic environment: Section 316 (b) P. L. 92-500. EPA Office of Water Enforcement, Permit Division, Industrial Permits Branch, Washington D. C., 59 pp.

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Hoese, H. D. and R. H. Moore. 1998. Fishes of the Gulf of Mexico. Texas, Louisiana and adjacent waters. Second edition. Texas A & M University Press, College Station, Texas, 422 pp.

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Nelson, J. S. 1994. Fishes of the world. Third Edition. John Wiley & Sons, Inc., U.S.A., 600 pp.

Robins, C. R. and G. C. Ray. 1986. A field guide to Atlantic coast fishes of North America. Houghton Mifflin Company, Boston, Massachusetts, 354 pp.

Whitehead, P. J. P., M. L. Bauchot, J. C. Hureau, J. Nielsen and E. Tortonese (eds.). 1984. Fishes of the North-eastern Atlantic and the Mediterranean. Vols. I-III United Nations Educational, Scientific and Cultural Organization (UNESCO). Printed by Richard Clay Ltd., U. K., 1473 pp.


**The Department of the Interior Mission**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.


**The Minerals Management Service Mission**

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.