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Some solutions to menhaden problems are proposed.

Menhaden and Power Plants—A Growing Concern

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INTRODUCTION

The energy crisis in the United States, at least the portion involving a demand for greater amounts of electricity than we can sometimes produce, is a real part of today's life, and projected needs for electrical power are startling. In 1971 about one-fourth of the total energy consumed was used to produce electricity. By the year 2000 it is estimated that 41 percent of what will be a more than two and one-half fold increase over the total energy used in 1971 will be utilized as electrical energy (Council on Environmental Quality, 1973). This rising consumption of electricity requires increased production, most of which is and will be supplied by fossil fueled and nuclear steam-electric generating stations. Such stations create considerable waste heat and require vast quantities of cooling water. Since rivers and streams suitable for cooling our larger generating stations are limited in number, and federal, state, and local requirements for their use are becoming more stringent, utilities are turning toward the coastal zone for a cooling water source. This is especially true in the northeastern and middle Atlantic states where coastal population densities are high and the demand for electricity strong.

The operation of electric generating plants along inshore waters is known to cause mass mortalities in marine fish, particularly in recent years among the commercially important menhaden. This article reviews the biology of menhaden, examines why and when power plants are hazardous to menhaden, and offers some solutions to the problems discussed.

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MENHADEN BIOLOGY

Atlantic menhaden (*Brevoortia tyrannus*) help support the largest commercial fishery in the United States. Primarily they are reduced to fish meal for poultry and livestock feed and to oil, for use in the manufacture of paints, inks, and sealants. Menhaden oil is also exported for use in edible products. Since the early 60s there has been a steady decline in the fishery due essentially to overfishing. Pollution and destruction of estuaries are additional burdens on fish stocks. A look at the habits and life history of the Atlantic manhaden will provide some understanding of when and why they may be vulnerable to the effects of power plants.

What is now described as a single population of menhaden (Nicholson, 1972) ranges from Nova Scotia to Florida (Reintjes, 1969). Menhaden become mature and spawn at 3 years of age. Spawning takes place in oceanic waters and the larger sounds and bays from spring to fall in the northern part of the range and from fall to spring in the southern part (Reintjes, 1969). Eggs hatch in 36-48 hours (Nicholson, 1972), and larvae enter the estuaries. Once able to swim, they move into low saline water (from 1 percent to fresh) where they metamorphose into juveniles (Wilkens and Lewis, 1971). After metamorphosis they school and appear to seek higher salinity water, and the estuary then functions as a nursery ground, offering protection and phytoplankton as food for the young menhaden during the summer months. Migration of juveniles to sea is generally triggered when the water temperature begins to drop in the late summer and fall. This movement occurs somewhat sooner in the higher latitudes because of earlier cooling in the estuaries. The migration is not always complete, however, and some young fish, probably late-comers into the estuaries, may overwinter in the deeper holes where warmer water accumulates[1] or in the estuaries of the lower latitudes from Chesapeake Bay to Florida (Reintjes, 1969) where lethal cold temperatures are less frequent.

The migrating menhaden move southward, often rather rapidly (Kroger, Dryfoos, and Huntsman, 1971), to an offshore wintering area south of Cape Hatteras, N.C. Here they congregate until spring when there is a general northward migration back to coastal waters, the larger and older fish moving farther north than the younger fish (Nicholson, 1971, 1972). Evidence indicates, however, that menhaden do not necessarily return to the same area from which they came the year before (Nicholson, 1972). An overall pattern of northward migration in the spring (and summer, also, above Chesapeake Bay) and southward in the fall persists throughout the life of menhaden, but after their first summer they do not generally re-enter estuary shallows. The largest concentrations of menhaden are usually found within 15 miles of the shore (Nicholson, 1971).

MENHADEN KILLS ASSOCIATED WITH POWER PLANTS

The dependence of young menhaden on estuaries makes them highly vulnerable to the activities of man. Since menhaden appear to be sensitive to many environmental changes, a man-caused modification in the nature of the estuary can produce deleterious effects resulting in an immediate fish kill, or delayed mortalities caused by altering the natural behavior of the fish. Menhaden kills associated with power plants have been attributed to six causes: heat shock, cold shock, impingement on

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[1] Pers. comm., A. L. Pacheco, NMFS Sandy Hook Laboratory, Highlands, N.J.

Figure 1.—Menhaden frozen into the ice along the Oyster Creek Power Station's discharge canal after the cold shock kill on 29 December 1972.

intake screens, gas embolisms, biocides, and entrainment.

Heat Shock

Heat shock is caused when organisms acclimated to a favorable temperature (or at least one below their upper critical limit) are suddenly exposed to a temperature that is substantially higher, frequently one that is approaching or above the critical limit. A substantial heat shock kill occurred during August and September 1971 near Northport, Long Island where a fossil-fueled power plant was releasing 266,000 gallons per minute (gpm) of heated water into Long Island Sound (Young and Gibson, 1973). The effluent temperature measured 37-38°C, about 15°C above ambient and clearly above the 33°C cited by Lewis and Hettler (1968) as a maximum temperature for the survival of juvenile menhaden. Schools of young-of-the-year fish moved into the effluent where they suffered sudden and lethal heat shock. Since juvenile menhaden sink when killed by thermal shock (Lewis and Hettler, 1968; Young and Gibson, 1973) the estimate of 200,000 fish killed was probably low. The power plant has recently increased its generating capacity, and now has a thermal discharge of 500,000 gpm.

Fairbanks, Collings, and Sides, (1971) report on a similar menhaden kill in the Cape Cod Canal near the Canal Electric Generating Station which occurred in the late summer of 1968 when the temperature at the mouth of the discharge flume reached 34.4°C.

When young menhaden make their late summer and fall migrations from the estuaries, they usually swim in rapidly moving, tightly grouped schools parallel to and within 1 kilometer of shore during their passage through the bays and sounds. A thermal effluent like the one at Northport is a barrier to migrating schools. Even though the heated water, as it flows from the discharge into a sound or bay, may "float" above the cooler water, surface-swimming menhaden may not avoid it by moving around or under the plume.

In May 1972, 20-30,000 adult menhaden died after entering a granite quarry lagoon used by the Millstone Point Nuclear Power Plant of Northeast Utilities as a receiving pond for discharge water. The probable cause of the kill was heat shock (U.S. AEC, 1972).

On 9 August 1973 a dilution pump failed at the Jersey Central Power and Light (JCP&L) Company's Oyster Creek nuclear station causing a temperature rise of 5°C (from 31°C to 36°C) in its 10-foot deep and 2-mile long discharge canal. Adult menhaden had moved up the canal, probably into the face of the dilution pumps where 270,000 gpm of cooler water from the intake canal was being pumped directly into the discharge canal for the purpose of temperature reduction. When the pump malfunctioned, the sudden temperature shift killed about 5,000 fish.

The kills at Oyster Creek and Millstone Point were facilitated by the entrapment of adult menhaden in the receiving canal and basin where the warm water was deep enough to lure the fish from the bays but too small to offer a route for escape. The upper lethal temperature for adult menhaden, though not yet investigated, is probably not much higher than the 33°C maximum for juveniles.

Cold Shock

Cold shock, the converse of heat shock, may occur when organisms living at a relatively high temperature are suddenly exposed to one much lower, usually near or below their minimum thermal tolerance. Cold shock has received considerable attention in central New Jersey where the Department of Environmental Protection won a suit against JCP&L for a kill in Oyster Creek during January 1972. This was the first of several fish kills at this site which have resulted from cold shock. An unscheduled shutdown of the 640 MWE nuclear station on 27 January 1972 caused colder (3°C) water to replace the heated (15°C) water (Anon., 1972a) which was being discharged into the canal at 460,000 gpm. Menhaden overwintering in the canal and those under the influence of the thermal plume in Barnegat Bay suffered cold shock. At least 500,000 fish were killed.

On 29 December 1972 the nuclear

plant again shut down. Moribund fish were reported by local residents on 30 December. On 8 January 1973 several thousand dead fish were found frozen in the ice along the edges of the discharge canal. As was true in the kill of January 1972, the majority of the dead fish were Atlantic menhaden. Both adults and young-of-the-year were killed (Fig. 1).

The temperature again dropped on 18 February 1973 because the plant shut down, and dead juveniles were found on 20-21 February, both floating on the surface, where they were exposed to gull scavenging, and on the bottom of the canal (Fig. 2) where they were inconspicuous to the general public. The kill exceeded 1,000,000 fish.

As mentioned, menhaden normally leave inshore waters when temperatures begin to drop. However, in the presence of a heated effluent, juveniles and adult fish, which would normally migrate from the area, are attracted to the warm water and are induced to overwinter. Some menhaden that are naturally overwintering in the area may also find their way to the warm effluent. When the plant shuts down during the winter, either purposely or accidentally, the sudden elimination of heated water can cause cold shock. This sequence of events occurred repeatedly at Oyster Creek.

Impingement on Intake Screens

Impingement of menhaden on intake screens that protect the circulating water systems of power plants from debris is probably a common occurrence. Two instances are given here. On 22 January 1973 several hundred juvenile menhaden were collected from the rotating screens of the Oyster Creek facility.[2] A much more severe kill occurred in September 1971 at the Millstone Point Nuclear Station. Young menhaden were hauled away by the truck loads, and the plant had to be closed down for several days because of fish clogging the intake.

During the fall migrations young menhaden may expose themselves to the high velocity current of a power plant intake. In situations where impingement deaths occur, the fish are unable to swim against the current and are drawn against the protective intake screens.

Gas Embolism

Gas embolism is a problem created by electric generating plants that was unanticipated by scientists and utility officials. Cool water that is saturated with air, or nearly saturated, can become supersaturated when heated. Fish swimming into supersaturated water will extract the air and utilize some of the oxygen. However, the partial pressure of nitrogen is higher than the partial pressure of that gas in the tissues, and the nitrogen vaporizes to form bubbles in the fins, under the skin, and in the vascular system. Symptoms of "gas bubble disease" are subcutaneous nitrogen bubbles, hemorrhaging, lesions, and exopthalmia.

During April 1973, the nuclear plant operated by Boston Edison at Rocky Point, Mass., released seawater supersaturated with nitrogen by being heated from 4°C to 20°C (Anon., 1973c). About 10,000 menhaden suffered gas embolisms similar to embolisms found in salmonids around dams in the Columbia River. The kill lasted for more than a week when, finally, the utility cut back power production by 70 percent to alleviate the situation.

Harvey and Cooper (1962) showed on a theoretical basis that because of the relative solubilities of oxygen and nitrogen, more nitrogen than oxygen can go into solution. Nitrogen is therefore usually blamed for the disease. Bubble growth, however, may also possibly involve oxygen and other gases. Supersaturated oxygen levels were recorded by the author from the Oyster Creek discharge canal during March 1971, although these were not associated with any fish mortalities.

Air solutions in seawater usually reach their peak concentrations during the spring when the water is still cold but just starting to warm. Even naturally supersaturated conditions are not uncommon (Stickney, 1968). An early arrival of menhaden in an area influenced by thermal additions, such as Rocky Point, may result in an outbreak of gas bubble disease.

Biocides

Numerous chemicals are used in conjunction with power plant operations which, if released into the water in large amounts, can be detrimental to finfish (Becker and Thatcher, 1973). Sodium hypochlorite, a commonly used biocide which prevents fouling in water circulating systems, was injected twice daily into the coolant water of the Canal Electric Generating Station. Chlorine residuals of 0.8 to 1.5 ppm caused several kills of juvenile menhaden during the late summer of 1968 (Fairbanks et al., 1971). Each kill involved from several hundred to several thousand fish.

Fairbanks et al. (1971) have determined through bioassays that 0.7 ppm chlorine is a significantly critical dosage to be lethal for young menhaden exposed to this concentration for 10 minutes. When concentrations such as this are released either through design or accident, and with a conceivable heat-chlorine synergism, menhaden schooling near the discharge may be killed.

Entrainment

Another hazard to menhaden is the entrainment of larval fish and their passage through a condenser system. During a conference on the pollution of Mount Hope Bay, Dr. Clarence M. Tarzwell (Environmental Protection Agency, 1972) stated that up to 164,507,000 larval menhaden per day were calculated to have been killed by passage through the Brayton Point Generating Station. Hydrostatic and mechanical shearing forces appeared to be the major cause of death. Marcy (1971) found that none of nine larval fish species examined survived passage through condensers at temperatures above 30°C (menhaden were not included).

These findings demonstrate the inadvisability of siting a power plant on an estuary. Menhaden and other fish that utilize the area as a nursery are highly vulnerable to power plant "predation."

[2] Pers. comm., Charles I. Gibson, Battelle Memorial Institute, W. F. Clapp Laboratories, Duxbury, Mass.

Figure 2.—Young-of-the-year menhaden that sank to the bottom of the Oyster Creek Power Station's discharge canal after a cold shock kill on 18 February 1973.

PUBLIC RELATIONS

In these days of ecological concern the managers of utilities are as sensitive to fish kills as conservationists. They are unfavorable for public relations and may, for example, create enough anxiety with local officials to cause the denial of building permits by planning boards. Such a denial ensued as a result of the heat shock kill in Oyster Creek. The Lacey Township Planning Board tabled, indefinitely, an application by JCP&L to build an additional nuclear station (Anon., 1973a).

The initial reaction of spokesman for utilities accused of causing fish kills is often defensive, which might be expected. For instance, JCP&L initially denied responsibility for their first and second menhaden kills, saying each time that most of the dead fish appeared *several days after* the plant had shut down (Anon., 1972b; Fishberg, 1973; Augustine, 1973). The sinking of the dead menhaden followed by floating bodies probably accounts for this time lapse. The value of menhaden is often depreciated: the Portland Press Herald (Anon., 1973b) quoted a Boston Edison Co. representative to the effect that the menhaden which died from gas embolism were "trash fish" and that the kill was "very small."

SOLUTIONS

Each power plant, depending on its size, where it is sited, and the biological communities present, faces environmental problems; some are common and some are unique. Combinations of these factors require plant engineering and design on an individual basis, and few generalities can be stated about design. One, possibly, is that long discharge canals are ecologically deleterious. They provide a body of water where organisms, whether entrained or simply residing in the canal, are exposed to high temperature for long periods of time. For an entrained organism, the longer the period of shock, the less chance for survival. Residents, such as menhaden, become acclimated to an artificial temperature regimen that is maintained by the plant. When the regime is altered by either a scheduled plant shutdown or a malfunction, the residents may be exposed to a lethal thermal shock.

Because of pressure by government and environmental groups there is an increasing effort on the part of utilities to design plants having a minimum impact on aquatic organisms, especially fishes. For example, the criteria which follow were set by Dr. Ruth Patrick of the Academy of Natural Sciences, Philadelphia (Jeffers, 1970, 1972) and are being used in designing the cooling system of the Calvert Cliffs Nuclear Generating Station (Jeffers, 1970, 1972; Sonnichsen, Bentley, Bailey, and Nakatani, 1973).

> 1. Condensers should be designed so that the temperature rise in the cooling water which passes through them is as low as practicable. This will avoid subjecting pumped organisms to temperatures above their thermal damage threshhold and will minimize thermal shock.
> 2. The cooling water intake to the plant should draw water from below the photosynthetic zone to minimize the entrainment of plankton and other microscopic organisms.
> 3. The intake velocity of the cooling water to the plant should be low enough to avoid disturbing the schooling and swimming patterns of fish and to permit ease of egress for those fish that swim into the intake basin.
> 4. The cooling water system design should utilize mechanical equipment to clean condenser tubes to minimize the use of biocides for fouling control.
> 5. The point of discharge of the cooling water should be located far enough out from the shore so as not to disturb the current patterns and temperature regimes of the shallow water areas and should provide ample opportunity for mixing of the warmed cooling water with the receiving waters.
> 6. The cooling water discharge should be designed to create a high velocity jet to induce rapid mixing with the receiving waters to minimize changes in natural temperatures and oxygen content.
> 7. The cooling water discharge should be designed to minimize the time at which the maximum temperature elevation exists. Short exposure times as well as a minimum temperature rise are important in protecting the aquatic life.

More recently, Cairns (1972) has proposed additional requirements so that by combining these criteria and adjusting them for a particular locale, it may be possible to draw water and dispose of waste heat by, as Cairns (1972) said, "using, but not abusing, existing ecosystems."

Prior to the siting of an electric generating plant along a coastal zone, a thorough understanding of the physical, chemical, and biological aspects of the ecosystem to be used is necessary in order to predict plant effects. Works by Ahn and Smith (1972) and the National Marine Fisheries Service (1972) provide some guidelines and groundwork for conducting such field studies.

Once an ecosystem is understood and found suitable for plant siting, the above mentioned criteria should be observed if a once-through cooling system is to be used. Possibilities for the design of a discharge include dilution pumps, large volume water flows to reduce the delta T, diffusion systems, high velocity jets, spray systems, and saltwater cooling towers. Intake structures, reviewed by Sonnichsen et al. (1973), should have a low approach velocity of the cooling water at the screens and possibly a means of guiding or removing fish to avoid entrapment. A more environmentally sound alternative to once-through cooling is a closed system using either cooling ponds, spray ponds, cooling canals, saltwater cooling towers, or heat exchangers. Most of these are discussed in great detail by Sonnichsen, Engstrom, Kolesar and Bailey (1972) and Roffman, Dagus, Edmons, Maxwell, Van Vleck, Grimble, and Rossie (1973).

Offshore nuclear generating facilities are now planned by Consolidated Edison (1971) and Public Service Electric and Gas Company (1972). These will consist of installations containing two 1,000 MWE barge-mounted units enclosed by a breakwater at depths between 40 and 100 feet (within the 3-mile limit). Clusters of four installations are envisioned, each several miles apart. Their ecological impacts are diverse and only speculative. For instance, vertically shifting plumes may be a problem. Still, the above criteria should generally apply, plus any design innovations needed to minimize their impact in this environment. One such innovation might be to draw bottom water and release it near the surface in order to take advantage of existing thermoclines.

Unfortunately, the enthusiasm for good environmental quality may dwindle as the shortages of energy become more acute and have a greater effect on daily lives. It is easy to be noble when we are not on the spot, but when the personal comforts and conveniences which we have made necessary to modern life become scarce, we may tend to become unyielding in our desires, and nobility may dissipate. With a greater energy crisis looming before us we should be even more vigilant in protecting natural ecosystems to ensure a continuation of menhaden and other fisheries resources.

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