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Impact of Cooling Waters on the Aquatic Resources of the Pacific Northwest

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INTRODUCTION

Aquatic animals, with the exception of aquatic birds and mammals, are cold-blooded or poikilothermous, which means that their internal body temperature approximates that of the environment in which the animal lives. Since the aquatic environment has a comparatively narrow range of temperature, fish and shellfish do not have wide temperature tolerances. They can never adjust their body temperature below or above that of the surrounding water; therefore, they suffer damage or death from temperatures higher or lower than their normal temperature range. In addition, the life processes, growth, and activity of cold-blooded animals are governed by the temperature of their environment.

The following discussions are related solely to the effect that man's industrial activities, especially electrical power generation, have or may have on the temperature of the aquatic environment of the Pacific Northwest area and the subsequent effect of these alterations on the aquatic biota.

The demand for electrical power in the United States generally, and in the Pacific Northwest specifically, is increasing at an alarming rate. The Bonneville Power Administration (BPA) of the U.S. Department of the Interior estimates that the firm energy sources in the Pacific Northwest will almost triple in the next 20 years. Since most of the economically feasible hydroelectric sites have already been developed, the bulk of the new power will be from thermal generation, both nuclear and fossil fuel, such as coal and oil.

Thermal nuclear power generation is very inefficient. Approximately two-thirds of the total heat generated is wasted and must be dissipated into the environment. This has caused concern for the aquatic environment and its biota since the waste heat from thermal electric plants is normally disposed of in rivers, lakes, estuaries, and the sea. A 1,000-megawatt thermal nuclear plant, with once-through cooling will discharge as much as 2,000 cubic feet per second of water heated an average of 19.4°F (10.8°C) above the ambient temperature in fresh water and 25°F (14°C) in salt water (Coutant, 1970). Little is known of the effects that the addition of such tremendous amounts of heat would have on marine resources. The major indigenous fishery resources of the Pacific Northwest are both cold-water and anadromous species. This creates special concern for their welfare with the advent of widespread thermal pollution in the aquatic environment. This report describes the present and predicted future sources and volumes of cooling waters returned to the marine environment in the region; it reviews the physical and biological effects that such cooling water may have on the marine resources.

SOURCES OF COOLING WATER

Present Sources

The Pacific Northwest has obtained almost all of its electric energy from hydrogeneration up to the present time. There are 161 hydroelectric projects in the region (Bonneville Power Administration, 1972). Because of a limited supply of alternate energy sources and a generous supply of hydropower, the Pacific Northwest has used electric energy at an even greater rate than the rest of the nation. However, most of the feasible hydropower sites have been developed, and the region's electrical suppliers are turning to steam electric generators, mostly nuclear fueled.

Each of the different methods of generating electricity has harmful as well as beneficial effects on the environment. Hydroelectric development, in the past, has blocked or otherwise hindered anadromous fish runs, in addition to inundating spawning areas. However, it has benefited the fisheries by controlling floods and releasing additional water during the low-flow periods in the late summer and fall. Steam-electric plants—particularly those that are nuclear-fired—return great quantities of heated water to the environment. Laboratory and on-site experiments have shown this to be detrimental to the aquatic life in the immediate area of the discharge. On the other hand, experiments have shown certain instances where heated water at safe levels has induced greater productivity and growth rates of aquatic animals (Bell, 1971).

There are numerous sources of thermal pollution in the waters of the Pacific Northwest, mainly around large metropolitan and industrial areas. These probably vary from purely heated water to a multitude of combinations of heated water with other pollutants. A survey of the lower Columbia River revealed 19 thermal pollution outfalls between Bonneville Dam and the mouth of the river. It was calculated that these outfalls put sufficient heat into the river during the summer to raise the temperature of the entire flow by 0.5°F (0.3°C). The shore water where the outfalls are usually located could be expected to increase more than 0.5°F.

The largest single source of man-made heat injected into the Columbia River comes from the Washington Public Power Supply System plant at Hanford, Wash. It was the largest thermal nuclear plant in the United States when it went into production in 1966 and it was the first in the Pacific Northwest. The electrical power produced at this plant requires the diversion of 1,240 cubic feet per second of cooling water from the Columbia River. This quantity of water diverted daily from the Columbia River was more water than used daily for domestic purposes in the entire state of Texas and twice the daily domestic consumption of the entire city of Los Angeles (Snyder, 1969). This volume of water is increased by 30°F (17 °C) over normal river temperatures as it is pumped through the condenser of the plant. The effluent cooling water from the Hanford plant is discharged into the mainflow of the Columbia River.

The only other large thermal electric plant operating in the region is the huge new fossil fuel plant at Centralia, Wash. It apparently does not contribute substantially to thermal pollution of the aquatic environment because it has cooling towers, and most of the heat is discharged via the towers into the atmosphere.

Most of the thermal power generation in tidewater on the west coast is in California where in 1968 there were 2 nuclear and 21 conventional plants; Oregon had 7 conventional plants and Washington only 3 (North and Adams, 1969).

Future Sources

As mentioned earlier, most of the economic hydropower resources will soon be developed and some authorities believe that by the early 1990's hydropower resources will be used to serve peak demands and thermal plants will operate as baseload plants. Figure 1 (Bonneville Power Administration, 1972) depicts the future dependence on thermal electric power in the Pacific Northwest. A hydrothermal program developed by BPA to meet the predicted demand for electricity calls for the construction of 20 thermal plants in this region by 1990 (Bonneville Power Administration, 1969). If these plants used once-through cooling, it would mean that approximately 32,000 cubic feet per second of cooling water would be returned to the environment at 18°F (10°C) above ambient. A volume of 32,000 cubic feet per second is approaching one-half of the low flow of the Columbia River. This volume of heated water could obviously have far-reaching effects on the environment.

The search for sites to locate the thermal nuclear plants has concentrated on the Columbia River, the

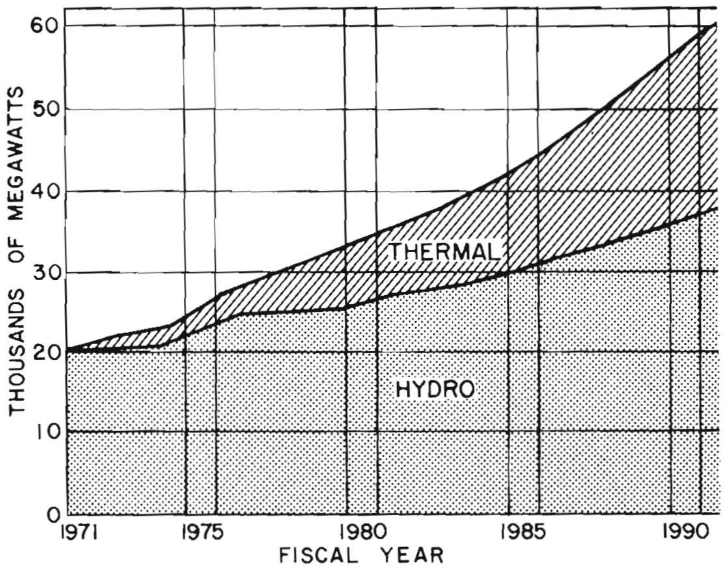

Figure 1.—Predicted future dependence on thermal electric power in the Pacific Northwest (Bonneville Power Administration, 1972).

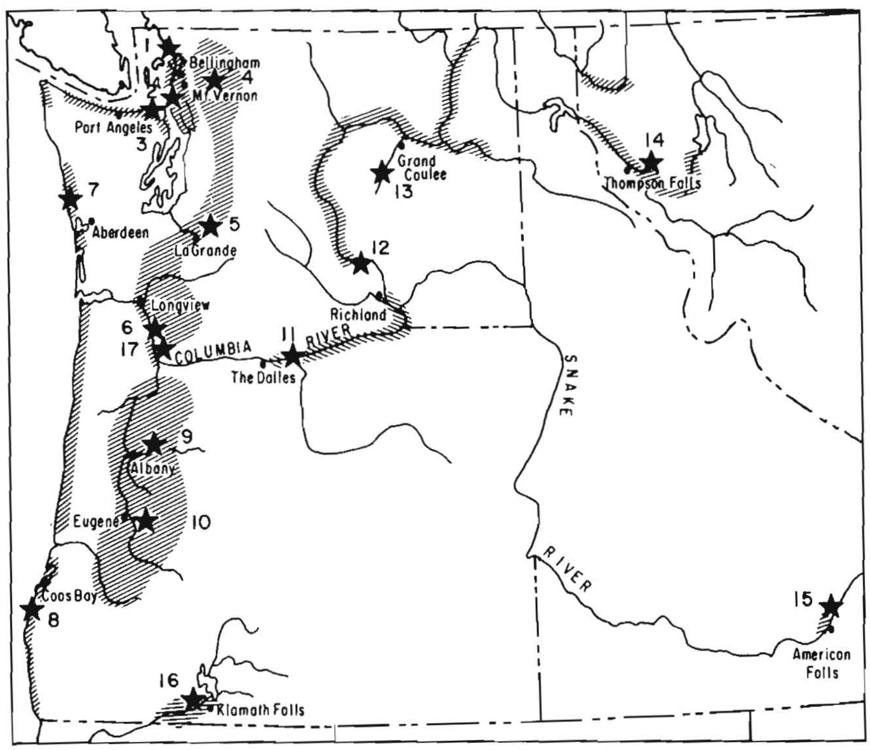

Figure 2.—Proposed location of thermal electric power plants in the Pacific Northwest. (From Snyder, 1968.)

coasts of Oregon and Washington, the Strait of Juan de Fuca, and Puget Sound (Fig. 2). However, possible sites for nuclear power plants have included northwestern Montana and southeastern Idaho (Battelle Northwest, 1967). It would be economically advantageous to locate the plants close to the major centers of industry and population, but many factors, especially the availability of cooling water, will govern the location of plants.

The Trojan Nuclear Plant at Prescott, Oreg., is scheduled to go into operation in 1976. Studies at the site by the National Marine Fisheries Service established that once-through cooling would be detrimental to anadromous fish runs of the Columbia River. To alleviate the problem, the builders (Portland General Electric, Eugene Water and Electric Board, and Pacific Power and Light) included a closed cycle, natural draft cooling tower which will essentially eliminate returning large quantities of hot water to the river. Figure 3 shows this very expensive structure. A similar plant is contemplated across the river at Kalama, Wash.; other nuclear plants are scheduled for construction on the Skagit and Chehalis rivers in Washington.

Floating offshore thermal nuclear power plants are a real future possibility (Russell, 1974). Two plants proposed for 3 miles off the coast of New Jersey will generate 1,150 megawatts each and pump 2 million gallons of cooling water per minute, heated 17°F (9°C), back into the sea. Offshore floating-nuclear-power plants (OFNPP) may be an answer to the lack of suitable onshore generating sites where adequate cooling water is available. Of course, a major question regarding the proposed OFNPP's concerns the effect they would have on the marine environment and resources.

PHYSICAL EFFECTS OF COOLING WATERS ON THE AQUATIC ENVIRONMENT

Temperature affects many physical properties of water including density, viscosity, vapor pressure, and solubility of dissolved gases. Both density and viscosity decrease with increased temperature which accelerates settling velocities and has an effect on the deposition of sediment and sludge in rivers, reservoirs, and estuaries.

Slight differences in density may cause stratification in bodies of water, inhibiting vertical mixing and oxygen transfer to lower waters. Sufficient oxygen is one of the basic requirements for most living organisms. The solubility of oxygen decreases with increasing temperature and may result in oxygen levels less than optimum for a healthy aquatic environment. Atmospheric nitrogen, which is not normally important to good water quality, may reach supersaturation through rapid warming or pressure reduction, as occurs in condenser systems, causing serious problems to fish. Increased temperature also increases the rate of chemical or biochemical reactions and, in the presence of biodegradable organic material, the biochemical oxygen demand may be so great as to deplete the oxygen supply.

Fast flowing streams or rivers have advantages over lakes or reservoirs in disposing of cooling waters. They rapidly transport heated water away from outfalls, minimizing temperature buildup at the discharge point. The turbulence eliminates stratification and makes the exchange of heat between the surface and the atmosphere more rapid. Surface exchange coefficients (U_c) for lakes are about 100 Btu (British thermal units)/ft^2 · day · °F (temperature difference between air and water). Impounded reaches reaches of the Columbia River have U_c values of 130 to 160, whereas values for swift-flowing reaches are from 200 to 300 (Battelle Northwest, 1967). Heat added to a river may be dissipated twice as fast from a swift-flowing section as from an impounded section. Calculations indicate that 85 percent of a 1°C (1.8°F) increase would persist 204 miles downriver in the summer but

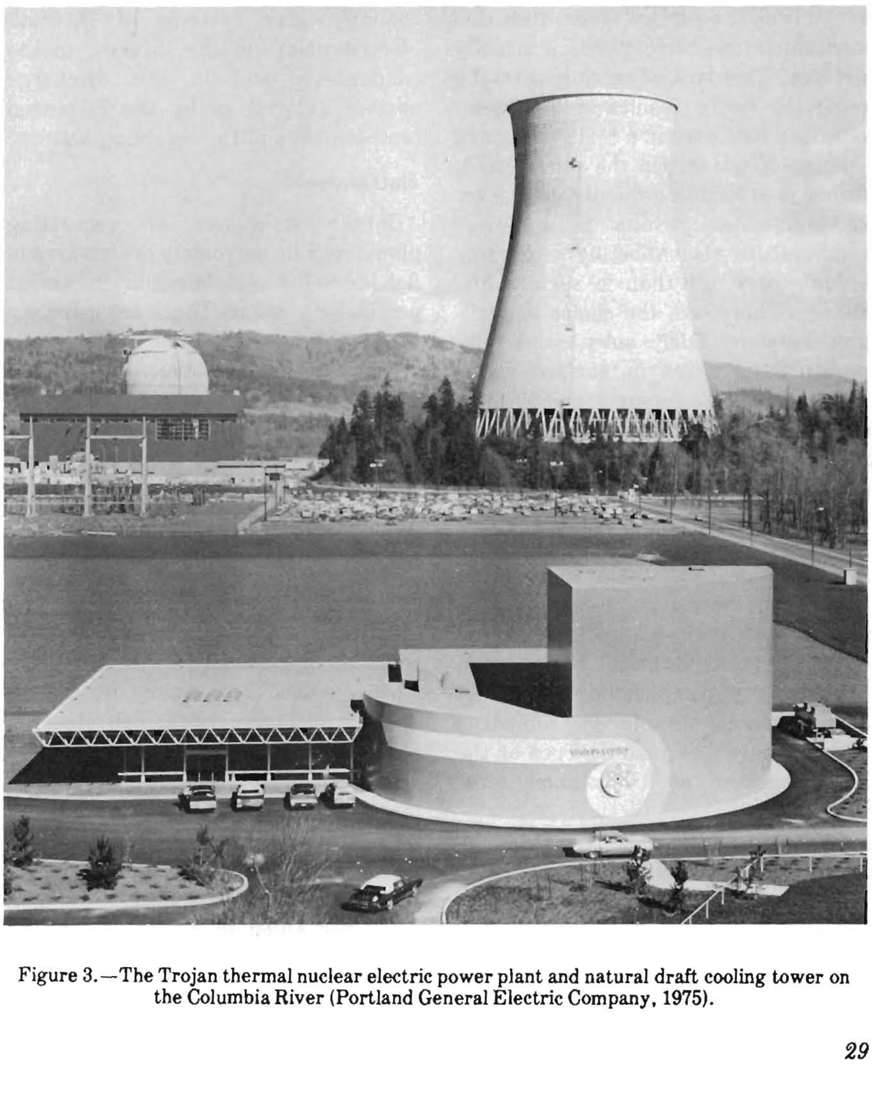

Figure 3.—The Trojan thermal nuclear electric power plant and natural draft cooling tower on the Columbia River (Portland General Electric Company, 1975).

only 65 percent would persist in the winter. It is difficult to generalize how long heat will persist because surface area, time, and current velocity all enter into the exchange process and each should be considered.

In a deep lake or impoundment, the water is usually stratified. In the summer the cool stagnant water of the bottom is separated from the warmer water of the surface by the transition zone. Heated water added to the surface will spread out in relatively thin layers (3 to 6 feet deep) over a larger and larger area until its density approximates that of the surface water. Very little of the effluent will reach the bottom until the fall of the year, at which time, the lake's stratification is broken and the waters mix.

The dissipation of heat from nuclear power plants is estimated to require about 2,000 acres of lake or impoundment surface for each 1,000 megawatts. Cooling water discharge to the surface of the receiving water generally remains on the surface where heat dissipation to the atmosphere is usually greater. This lack of mixing with the receiving water results in high temperature increases in a relatively small volume of water. On the other hand, diffusion of heated effluent into the receiving water results in a lower temperature rise affecting a greater volume of water than in surface discharge. Therefore, the choice is available between fairly substantial temperature increases in surface water versus moderate temperature increases in a much greater volume of the receiving water. The preceding would also be true of a saltwater installation with the exception that the pattern of heated waters would be much more complex because of the periods of flood, ebb, and slack tides and the intrusion of fresh water. An enclosed body of water like Puget Sound could have a very complicated pattern of heated water dissipation compared with the Strait of Juan de Fuca or the ocean because of its complex tidal patterns.

Heat dissipation in estuaries is complicated by the natural stratification caused by the intruding wedge of salt water on the bottom and the fresh or brackish water on top which would be reinforced by the addition of heated water. Although the general movement of the water would be seaward with the flow of the river, there would be the added complexities of the tidal cycle.

Dissipation of heated water at a marine site depends on many things, including ambient water temperature, air temperature, tidal currents, freshwater influx, and plant intake and discharge arrangements. In general a 2,000-megawatt plant (many are planned) will affect the immediate area of a plant to a radius of 6,000 yards. Beyond this point the temperature difference would be too low to maintain stratification (less than 3°F (2°C). Each plant and site is a special case and generalizations are of questionable value, but fairly accurate predictions of the thermal regime expected at a particular site may be made (Adams, 1969).

BIOLOGICAL EFFECTS OF COOLING WATER

Marine organisms are affected by cooling water systems of thermal-electric plants at the intakes, in the condensers, and in the discharge system as well as by the increased temperatures of the receiving waters.

Entrainment

Intake structures of generating plants may be extremely destructive of fish life under certain conditions and at particular seasons. There are usually a series of gates, trash racks, and screens at an intake structure, grading from coarse (to eliminate heavy debris) down to fine screen of 3/8- or 1/4-inch mesh to exclude finer particles that could block the 1-inch diameter condenser tubes. Fish may be impinged and injured or killed at any one of these, depending on the size of the fish and the velocity of the water at the structure. Impinged fish and debris are removed periodically by some mechanized means, but usually no special effort is made to save the fish. Records to assess the true loss of fish caused by impingement at generating plants are few but those that do exist demonstrate the magnitude of the problem. At a generating plant on the Hudson River in New York, almost 1½ million fish were killed in a 2-month period during the winter of 1969-70 (Edsall and Yocom, 1972); the testing of two new pumps at this plant killed so many fish in one month that the operating company was fined over $1½ million (Sport Fishing Institute, 1972a). Impingement takes it toll of aquatic organisms in either the freshwater or marine environment and could be a serious problem wherever thermal electric plants are built.

Myriads of important marine organisms are too small to be screened from the condenser cooling system. They include: fingerling fish, fish eggs and larvae, eggs and larvae of invertebrates, and the balance of the zooplankton that comprises important members of the marine food chain. These small organisms are carried through the condenser cooling system where they encounter many adverse conditions: collision with the internal surfaces, extreme temperature shock, pressure and temperature changes causing gas embolism, and toxic chemicals used as biocides. Several studies have been made of the survival of fish eggs and larvae in condenser systems, almost all of which indicate a high loss. At a thermal nuclear plant in Connecticut, up to 80 percent of the entrained larvae died in passage through the condenser cooling system and none survived passage through the condenser and discharge canal when discharge temperatures were 86°F (30°C) and above (Marcy, 1971). Similar results were experienced at plant after plant where studies have been made of survival of larval fish entrained in cooling systems (Marcy, 1973). Striped bass, menhaden, whitefish, herring, and smelt larvae have suffered heavy losses through entrainment. Losses similar to those mentioned above could be expected at plants in the Pacific Northwest having once-through cooling; many of the same or similar species are present, in addition to Pacific salmon, genus *Oncorhynchus*. Salmon fingerlings, especially pink, *O. gorbuscha*, and chum salmon, *O. keta*, would be vulnerable to power plant entrainment since they migrate in dense schools near shore where intakes may be located.

Distribution

One of the obvious biological effects of power plant discharges of waste heat in other parts of the country has been a local alteration in the seasonal distribution of fishes. It is a natural tendency for aquatic organisms to seek the temperature where growth and other life processes are at an optimum. Therefore, they may seek cool water in the summer and warm water in the winter. Elevated temperatures in discharge areas may collect numerous species of warm water fish in summer while repelling cold water species. In winter, when effluent temperatures may be tempered by lower river temperatures, all species may be attracted.

Most fish are able to adjust to or avoid temperature changes if they are gradual. However, the operation of power plants can cause both rapid increases and decreases of temperature in the vicinity of the discharges. Reversing the flow through condensers to remove fouling may cause sharp temperature increases, killing fish in the discharge area. Plant shutdowns in winter may expose the collected fish to equally lethal cold-water shock. These disasters have befallen manhaden, anchovies, bluefish, striped bass, and herring—species similar to those in this area. Fish kills as great as 25 tons per month have been estimated for the plants operating between San Diego and Ventura on the California coast. Although some of these problems may be moderated in Puget Sound and coastal locations in the Pacific Northwest because of a more stable year-round water temperature regime, serious loss of fish could result. It has been found that the fully marine and sublittoral species are less tolerant of high temperatures than estuarine or intertidal forms.

Temperature Tolerance

The chemical and biochemical processes of an animal's body accelerate with increasing temperature; normally the metabolic rate doubles with each 19°F (11°C) increase. As temperatures rise, an animal's respiration rate increases along with the heartbeat rate, which consequently increases the demand for oxygen. At higher temperatures the hemoglobin of the blood has reduced carrying capacity for oxygen. The combination of increased demand for oxygen and decreased efficiency for obtaining it causes a severe stress on the organism. This may eventually cause death or one or more of the many sublethal effects.

Several extensive bibliographies on the effects of increased temperatures on aquatic organisms have been prepared (Naylor, 1965; Kennedy and Mihursky, 1967; and de Sylva, 1969). Much of the work is concerned with freshwater rather than marine life, but one recent report has compiled a schematic representation for thermal requirements for different life processes of Pacific salmon (Fig. 4).

The upper and lower lethal temperatures depend on the temperature at which an organism has been acclimated. There are, of course, upper and lower limits above and below which an organism is unable to survive, regardless of acclimation (Brett, 1956). Temperature acclimation and thermal tolerance information is useful in many ways, but it does not provide information on the condition of the organism before it reaches the lethal temperature or of the irreversible physiological effects that may occur well below the lethal temperature.

Tolerance to temperature increases may depend on an organism's geographical range as well as its ecological habitat. For example, tropical animals may live at temperatures only a few degrees below their death point, while arctic species may normally live many degrees below their upper thermal death point. Adult Arctic fishes can usually be acclimated to temperatures far above their normal temperature, whereas tropical species ordinarily cannot be acclimated to temperatures much higher than their normal temperatures. Temperate species have generally exhibited a wide range of experimental lethal temperatures.

Gradual acclimation to higher temperatures increases an organism's ability to survive high temperatures but decreases its ability to survive low temperatures. This accounts for the great loss of fish collected by heated water in the winter that are subjected to sudden cold water by a plant shutdown. Most marine organisms seem to be able to adjust to increasing temperatures more rapidly than to decreasing ones.

The natural habitat of a particular species influences its range of temperature tolerance. Estuarine species are normally more tolerant of temperature fluctuations than sublittoral or littoral species since temperatures fluctuate more in an estuary than in the sea. Intertidal species are more tolerant for the same reason. A review of the literature reveals that eggs, larvae, and young fish are generally less tolerant of increased temperatures and would therefore suffer a greater loss because of this and their inability to avoid the heated effluents.

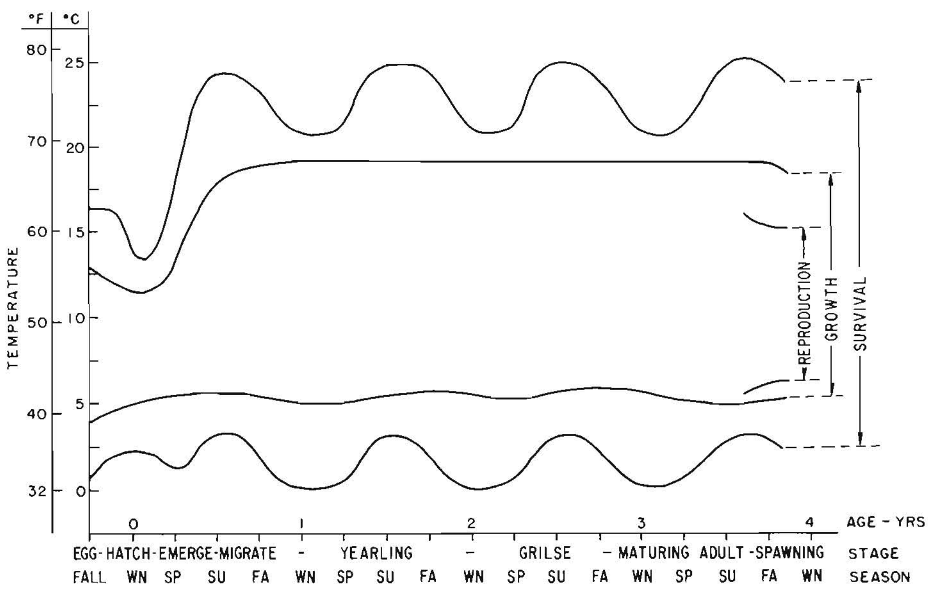

Figure 4.—Thermal requirements for various life processes of salmon. (From Brett, 1970.)

Sublethal Effects

The preceding paragraphs mention the most obvious of the effects that cooling systems and cooling waters have on marine organisms. These are the direct lethal effects where the end result is a dead fish decaying on the beach. The sublethal effects may be even more important, but they are usually much less obvious. These sublethal effects include increased susceptibility to predation and disease; effects on metabolism, growth, reproduction, behavior, the loss and damage of zooplankton; and synergistic effects.

Predation

Increased susceptibility to predation is one of the effects of sublethal exposure to increased temperatures, especially for juvenile fishes. Various researchers have found that a sublethal treatment to increased temperatures caused fry of sockeye salmon, *O. nerka;* yearling coho salmon, *O. kisutch;* juvenile chinook salmon, *O. tshawytscha;* and juvenile rainbow trout, *Salmo gairdneri*, to be all significantly more susceptible to predation than similar individuals not subjected to higher than normal temperatures (Sylvester, $972; Coutant, 1973). The thermal dose necessary to cause this susceptibility to predation was, in some cases, only a fraction of that necessary to cause loss of equilibrium in test fish.

Other sublethal effects of entrainment in the cooling and discharge systems of a thermal power plant may also increase the vulnerability of animals to predation. These include physical shock and abrasion, the effects of chemicals used as biocides, and the effects of temperature increases and pressure changes that cause gas embolisms. Gas embolism may either kill the fish directly or render it susceptible to predation. Power plants with once-through cooling could increase the rate of predation on Pacific Northwest species, especially on juvenile salmon that might be entrained or caught in the discharge plume.

Disease

The incidence of fish diseases (bacterial and parasitic) increases with elevated temperature. This relationship has been observed and studied in hatchery operations for many years. A review of the literature revealed that increased temperature was an important factor in most fish diseases (Ordal and Pacha, 1967). Studies with juvenile salmon and trout demonstrated that increased water temperatures intensified the effects of vibrio disease, kidney disease, furunculosis, and columnaris. Columnaris disease has been found to be exceptionally virulent during periods of high temperature. High temperatures in the Columbia River during the summer of 1941 and the consequent outbreak of columnaris disease decimated the sockeye salmon run that year. The literature is replete with incidents relating high temperatures to serious parasitic and bacterial diseases among aquatic organisms. Although cooling waters probably do not contribute significantly to fish diseases in the area at present, improperly located plants and discharges could cause problems in the future.

Reproduction

Spawning by marine animals may be stimulated by very slight differences in temperature. These changes may be as small as 1° or 2°C for some marine species. Truly oceanic species are usually more stenothermal (restricted to a narrow range of temperature) than estuarine species. A decrease in temperature usually delays spawning whereas an increase usually hastens spawning. Any alteration in spawning time could be harmful if the extremely critical balance of development, hatching, and availability of proper food for the young larvae is disturbed.

Some marine species, when exposed to higher than normal temperatures, do not spawn until returned to ambient temperatures; others may never spawn. Studies by the National Marine Fisheries Service revealed that temperature-treated female eulachon, *Thaleichthys pacificus*, of the Columbia River retained their eggs, whereas the control group spawned normally (Blahm and McConnell, 1971). Eggs of greenlings (*Hexagrammos decagrammos* and *H. stelleri*) subjected to treatments simulating conditions of tidal action and elevated temperatures from cooling waters did not hatch[1].

An increase of 18°F (10°C) could cause temperatures as high as 75°F (24°C) in condenser systems and in confined areas near outfalls in Puget Sound during the warmest months of the year. Very moderate temperature increases have been found to be lethal to Puget Sound Dungeness crab, *Cancer magister*, eggs (Strober and Salo, 1973). An 18°F increase in the cooling water from Puget Sound could cause these lethal temperatures in the condenser system in even the coldest months. Moreover, the eggs of marine species are buoyant and must remain near the surface for proper development. An increase in the water temperature could lower the density to a point where the eggs would sink and not develop.

The intake, condenser cooling, and heated water discharge systems of a thermal power plant could have an adverse effect on reproduction, depending on the proximity to important spawning areas and the life history pattern of the species. Gravid females and their eggs could be damaged by the intake system or by entrainment in discharge waters; spawning time could be altered. Eggs and larvae passed through a condenser cooling system would almost surely be damaged or killed.

Migration

Although few studies have specifically related temperature to the migration of adult anadromous fish, there is evidence that temperature is one of the important factors in the timing of migrations in the Columbia River (Coutant and Becker, 1968). There are records of abnormally high temperatures diverting or delaying migrations of Columbia River salmon (Fish and Hanavan, 1948; Major and Mighell, 1967), and experiments by the Bureau of Commercial Fisheries (now the National Marine Fisheries Service, NOAA) at Bonneville Dam indicated that adult salmon and steelhead preferred ambient or cooler water tem-

[1]Patten, B. G. 1974. High temperature tolerance of eggs and planktonic larvae of the kelp greenling, *Hexagrammos decogrammus*, and white spotted greenling, *H. stelleri*. Unpubl. manuscr. Natl. Mar. Fish. Serv., NOAA, Seattle, Wash., 11 p.

peratures over channels with water temperatures above 70°F (21°C).

Zooplankton

Zooplankton consist of a wide variety of animals, ranging from the smallest protozoa to the eggs and larvae of fishes. The importance of this collection of free floating organisms drifting with the tides and currents cannot be overemphasized. They include the early life stages of most marine species as well as essential food organisms for fishes.

Various studies have been made of the effect of increased temperature and entrainment on zooplankton (Heinle, 1969). Passage through a condenser system may cause mortalities of over 80 percent—if lethal temperatures are reached, and serious sublethal effects may be suffered by zooplankton that survive the passage. Reproductive potential and hatchability of eggs may be seriously reduced.

The mass of zooplankton is astoundingly large. In a study of the distribution and abundance of zooplankton in relation to entrainment in condenser cooling systems in Puget Sound, it was calculated that a 1,000-megawatt plant with once-through cooling could entrain up to 4.5 tons of zooplankton per day during the months of greatest abundance. It was estimated that projected power production on Lake Michigan using once-through cooling would kill 9.8 billion pounds of zooplankton annually. Destruction of this magnitude must certainly have detrimental effects on zooplankton populations.

CONCLUSIONS

It may be concluded that the impact of thermal effluent on the marine resources of the Pacific Northwest is small at the present time. The bulk of the electrical power in the area is from hydropower generation. The only thermal nuclear generating plant in operation is at Hanford, Wash., on the upper Columbia River, and the fossil-fueled steam electric power stations are widely scattered about the area. The Trojan nuclear plant on the lower Columbia River, scheduled to start operation in 1976, will have onshore cooling to protect the environment.

Predictions for future power needs, which will be supplied mainly by thermal nuclear generation, are so great that if once-through cooling is employed, vast quantities of heated water will be added to the area's aquatic environment. The foregoing review of the effect of cooling waters and condenser cooling systems on the aquatic environment and biota make it obvious that the construction of 20 or more thermal nuclear plants in the Pacific Northwest may have a very significant impact on marine resources.

A ruling announced by the U.S. Environmental Protection Agency on 2 October 1974, requires closed-cycle cooling systems on all steam-electric power stations starting operations after January 1974 (Sport Fishing Institute, 1972b). Cooling towers or artificial cooling ponds will be required at most plants to reduce discharge of heated water into streams, lakes, and presumably, bays and estuaries. Apparently the impact has not yet been shown to be great enough to require onshore cooling for coastal plants. It is not clear if this ruling applies to enclosed bodies of salt water like Puget Sound. Once-through cooling in such an area could have an extensive impact on the marine resources and should be avoided.

Extensive physical and ecological studies should be made of any proposed thermal power plant site well ahead of construction to allow adequate planning to minimize the impact of the plant on the marine environment and biota. These studies should be made regardless of the proposed location of the plant—offshore, coastal, or inland. With onshore cooling at most plants and adequate planning to protect the environment, the impact of cooling waters on the marine resources should be minimized.

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