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Thermal Pollution, Aquaculture and Pathobiology in Aquatic Systems [1] [2]

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Thermal Loading in Aquatic Systems

The term, thermal pollution, has been used with increasing frequency in scientific, governmental and public communications media. Used properly, thermal pollution means a man-produced unnatural temperature change that causes alterations in an aquatic system to the extent that other legitimate uses are impaired. "Although there are many causes of changed temperature regimes in the aquatic habitat, such as from dams, irrigation practices and industrial waste heat, one specific area, the steam electric station (S.E.S.) industry, appears to pose the greatest threat. This industry has the greatest non-consumptive industrial demand for water as a heat transfer medium" (Mihursky and Kennedy, 1967. pg. 20). Water requirements of this industry have been increasing at a rate much faster than population growth (Figure 1). Electricity demand in various areas of the United States reveals a doubling time of from 6 to 10 years. Projecting these figures from a 1960 base year gives an increase of 30 to possibly 256 times by 2010 (Mihursky and Kennedy, 1967).

Present S.E.S. discharge temperatures are generally about 5 to 15°C above ambient. However, engineering designs on new installations are generally producing temperature increases from 5 to 8°C in an attempt to meet new water quality standards.

Most S.E.S. now in operation have an open system — once pass design, whereby water from a river, lake or marine source is pumped into the installation, passed through heat exchangers and then returned to the natural water supply. Present individual S.E.S. water needs are generally below 1 million gallons per minute.

Trends within the industry, however, are causing significant increases in cooling water requirements at a given plant site. S.E.S. designs are larger than ever before and are still growing. Also, the move to less efficient nuclear designs requires more cooling water per kilowatt of electricity produced. The rule of thumb generalization is that for every kilowatt of electricity generated, there are two kilowatts of waste heat to be dissipated.

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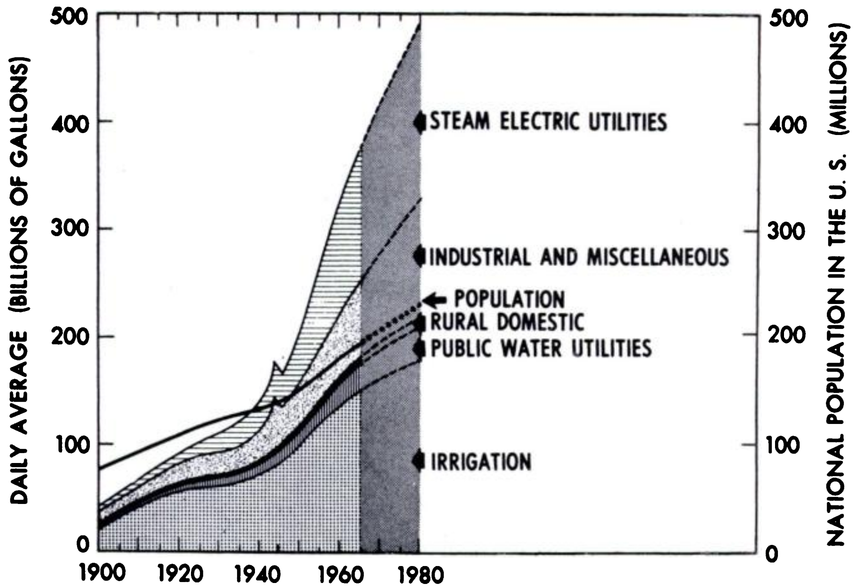

FIGURE 1. *Population growth and water use categories from 1900 to 1980. Note the increasing allocation to "Steam Electric Utilities" from 1950 to the present. (after Picton, 1960)*

Although most presently operative S.E.S. are less than 1,000 megawatts (MW) (1M = 1,000 kilowatts) capacity, those under construction or just beginning to operate are 1,000 to 2,000 MW. It is anticipated that future single installations may reach 4,000 to 8,000 MW capacities. The latter installation, if present open system — once pass designs are employed, could require daily, over 60 square miles of water, one foot deep for cooling purposes (see Sorge, 1969; and North and Adams, 1969, for additional data on industry).

The Role of Temperature in Aquatic Systems

Temperature has been properly referred to as the "master factor" in aquatic habitats and has been described as having lethal, directive and controlling effects on the whole organism (Fry, 1967). Temperature can be lethal in that certain high or low levels can directly cause mortalities, directive in that it influences daily and seasonal behavior, controlling in that it effects biochemical reaction rates and consequently influences metabolic rates. Brett (1960) has emphasized that different life history stages may have different temperature requirements and also that requirements vary with season (Figure 2).

That temperature tolerances of aquatic organisms can be exceeded by thermal discharges has been reported by Trembley (1965) and Coutant (1962) for the Delaware River; Churchill and Wojtalik (1969) for the Green River, Kentucky; and Mihursky (1969) for the Patuxent Estuary, Maryland. In recognition that direct damage can occur as a result of excessive artificial heating, especially in relatively restricted water circulation and supply areas, the S.E.S. industry is now altering its site locations, engineering designs and is also trying to obtain more rapid dilution

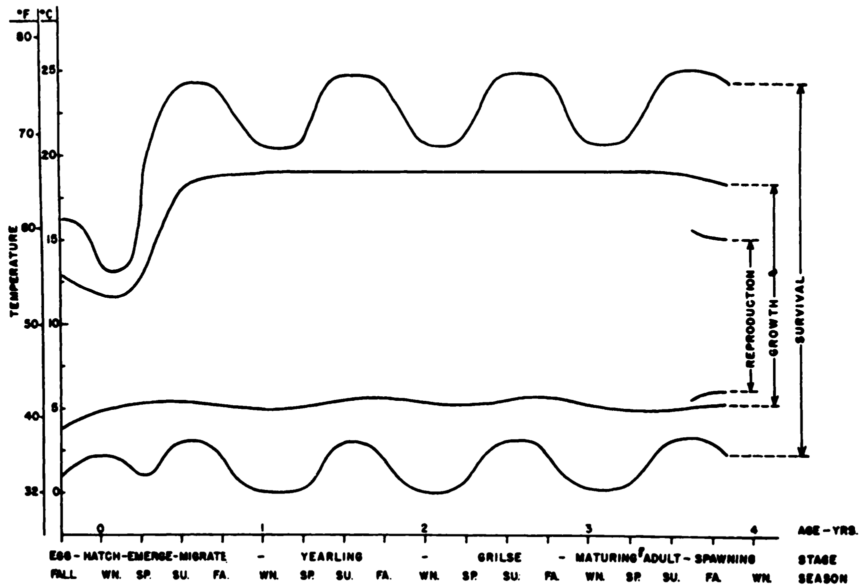

FIGURE 2. *Temperature and life history stage relationships for the sockeye salmon. Temperatures that will allow the animal to complete the various life history stages or functions are listed on the Y axis. Note that reproductive requirements are more restrictive than those for growth and that the latter are more restrictive than those permitting survival. Also note that the growth and survival requirements for early life history stages are generally more conservative than those for the adult even at spawning. (after Brett, 1960)*

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of its waste heat (Mihursky, *et al.* 1970). Thus, future patterns of waste heat will probably show extensive areas of a low temperature increase as opposed to local areas of high temperature increase. An important question remains to be answered by aquatic investigators: "What are the ecological consequences of extensive low level, unseasonal temperature elevations?"

Temperature Stress and Aquatic Pathobiology

Pertinent to the field of pathobiology is the role of temperature at a level that may result in a sub-optimal physiological condition. Such a physiological state obviously presents an opportunity for pathogenic organisms to overcome their host species. As Rene Dubos (1955) has stated: "There are many situations in which the microbe is a constant and ubiquitous component of the environment but causes disease only when some weakening of the patient by another factor allows infection to proceed unrestrained, at least for a while."

A number of scattered publications indicate temperature changes are often associated with increased incidence of fish diseases. Sinderman (1966), for example, in his excellent review on disease of marine fishes mentions the relationship between temperature and disease. In discussing a myxosporidian *(Kudoa clupeidae)* infection of Atlantic herring he states (pg. 48) that the distribution of the disease . . . "has been attributed largely to summer sea water temperatures, although other factors may be involved." de Sylva (1969) has recently summarized the work of a number of investigators who related disease occurrence to high temperature, viz. Sockeye salmon *(Oncorhynchus nerka)* and a bacterial infection on the Columbia River (Brett, 1956); salmonids and kidney disease, furunculosis, *Vibro* disease, and *Columnaris* (Ordal and Pacha, 1967).

In the summer of 1963 a massive kill of white perch *(Roccus americanus)* occurred in the Chesapeake Bay system. Research subsequently demonstrated that a *Pasteurella*-like organism was probably the responsible agent (Snieszko, *et al.* 1964; Janssen and Surgalla, 1968). Allen and Pelzar (1967) screened internal organs of white perch for bacterial isolates. They identified 7 major groups representing *Pasteurella, Bacillus, Achromobacter, Pseudomonas, Aeromonas, Enterobacter,* and *Micrococcus.*

Several of the isolated bacterial species, in addition to the *Pasteurella*-like species, were inoculated intraperitoneally in white perch and a number were found to cause infection and death. They concluded (pg. 152), "These findings indicate that there are organisms present in healthy white perch with the potential to infect and cause death if present in large numbers. This suggests the possibility of opportunist organisms multiplying and causing infection at the expense of fish which are in a stressed condition due to some alteration in the environment." Significantly, this epizootic occurred in the Chesapeake system during a period of high natural temperatures (Figure 3).

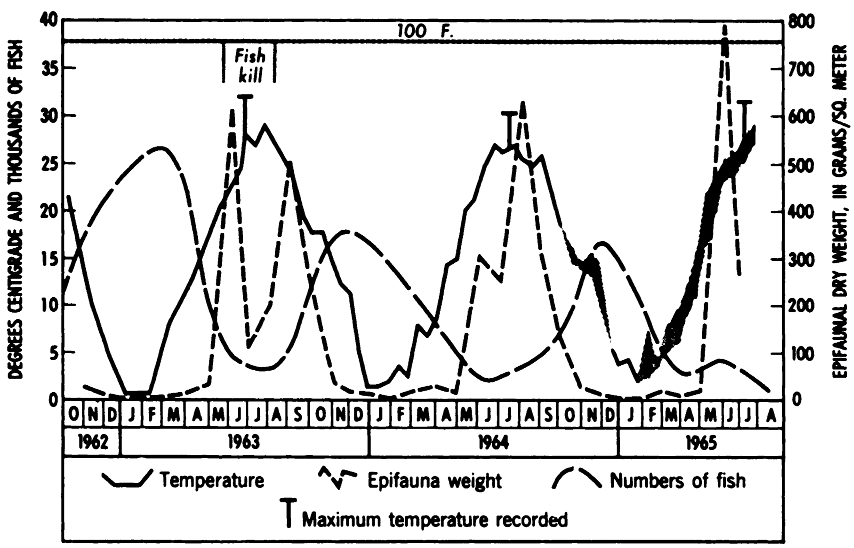

FIGURE 3. *Plot of temperature, epifaunal weight, and numbers of fish caught by channel trawling. These data coincide with the 1963 white perch mortality and suggest that temperature may have played a role in the massive fish kill. White perch dominated trawl catches and the reduction in total fish numbers beyond the summer of 1963 is due to a lowering of white perch in the catch. Summer channel trawl catches are generally lower than other seasons reflecting unavailability of fish to the gear. (after Mihursky and Cory, 1965)*

Similarly, the Bay region has experienced high summer mortalities of the soft shelled clam *(Mya arenaria)* in recent years. This clam in the Chesapeake is approximately at its southern limit of distribution on the east coast of the United States. Data from our laboratory indicate this shallow water shelf species is quite intolerant to temperature increases above those that normally occur in Chesapeake surface waters during summer periods. Although cursory screening has not been able to identify the exact reason for the mortalities (Pfitzenmeyer, H. T., 1970 per comm.) it is suspected that a temperature related microbial infection is a possible causative factor that should be explored.

Thermal Biotic Predictive Models and Ecological Death

Research at our laboratory has produced data on temperature effects on mortality, metabolism and activity on a wide variety of estuarine organisms (Mihursky 1969; Mihursky, *et al.* 1967; Mihursky, *et al.* 1968; Mihursky, *et al.* 1969). We have recently developed thermal-biotic predictive models that describe two categories of temperature relationships to estuarine fauna. One category defines that level of temperature or temperature change that is still within the optimal requirements for the species being considered, optimal with regard to energy conversion efficiencies within the whole organism as determined from respiration and activity data. The other category defines that level of temperature or temperature change that is sub-optimal. This latter category recognizes temperature levels can prevail that would not kill immediately but would reduce energy conversion efficiencies, result in reduced physiological condition, alter predator-host, host-parasite and host-disease relationships (Figures 4 and 5).

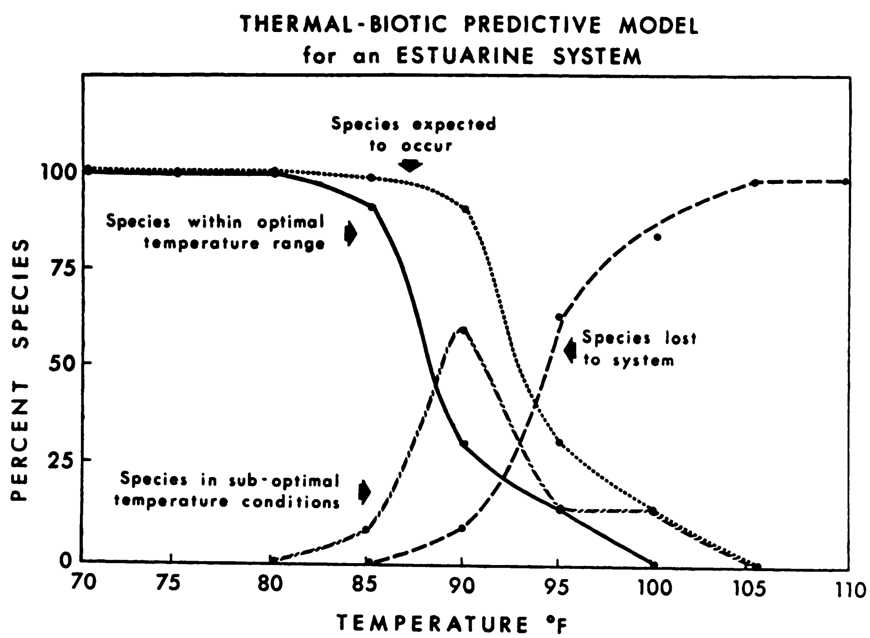

FIGURE 4. *Thermal-Biotic Predictive Model for an estuarine system. (summer conditions)*

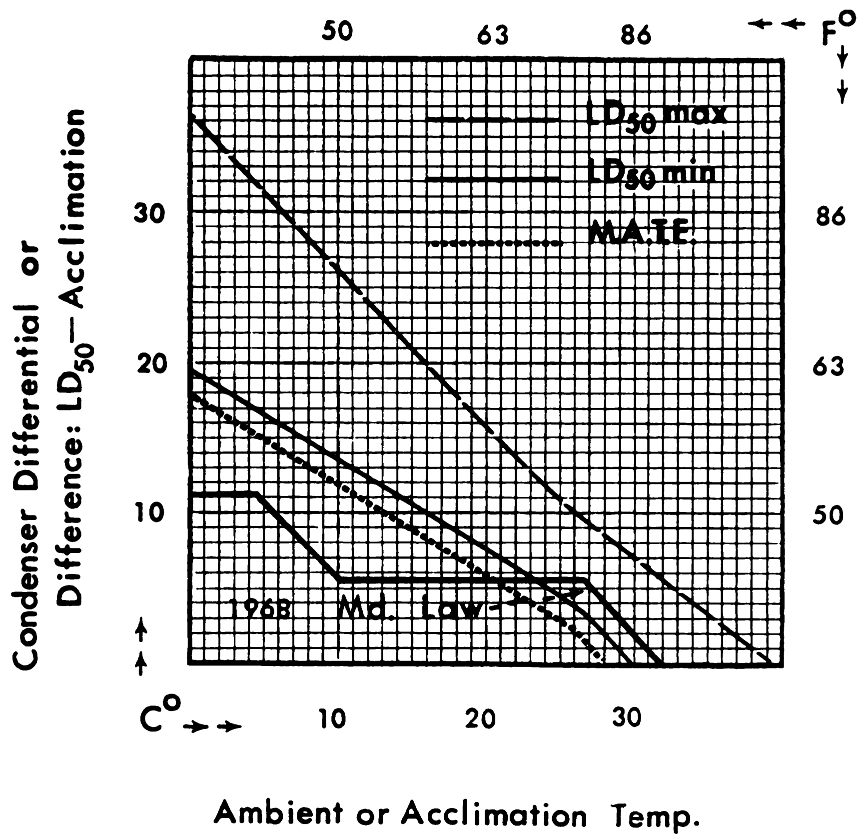

FIGURE 5. *Application of the Predictive Model. The dotted line, M.A.T.E. (= maximum allowable temperature elevation), is an extrapolation that is more conservative than the LD_{50} minimum line, and is suggested as an ecologically safe level of temperature change that might be permissible throughout the various seasons.*

Except for some research work on Columnaris disease in Sockeye salmon in the Columbia River around thermal discharges from the Hanford nuclear reactors (Fujihara and Tramel, 1969), little host-disease work has been done at heated water discharge sites. de Sylva (1969), however, has reported a high incidence of fungus disease in a marine fish species at a S.E.S. in Florida, but cautions that no formal investigations have been undertaken to understand the relationship.

Other Environmental Stress Factors from S.E.S. Operations

A number of operational factors from S.E.S. other than temperature are responsible for having detrimental effects on aquatic organisms. Chlorine, which is used as a biocide to keep heat exchange surfaces clean, has been reported as one of the agents that damages organisms such as phytoplankton and zooplankton which are entrained in cooling water supplies of S.E.S. (Heinle, 1969; Morgan and Stross, 1969). Loss of heavy metals due to corrosion and/or erosion of heat exchange surfaces has been reported responsible for excessive copper accumulation and greening in shellfish (Roosenburg, 1969). Mechanical effects to organisms from S.E.S. intake screening devices or from pumping activity are also known causes of damage. Thus, a number of S.E.S. operating characteristics can contribute to physical and physiological impairment of aquatic species.

Recycling of Waste Material, Aquaculture and Pathobiology

Investigators have emphasized the need to re-use and recycle waste materials rather than haphazardly release these materials in an uncontrolled and undirected manner into the environment. It would be advantageous if it were possible to recycle waste materials into useful foodstuffs. Mattoni, *et al.* (1965), for example, reported on a system whereby algae were grown in mass culture with the aid of a fertilizer effect from treated sewage water. The algae were concentrated by an evapo-drying technique and used as chicken food. Mihursky (1967; 1969) has discussed the possibility of combining domestic wastes and waste industrial heat with aquaculturing systems in order to produce food material (Figure 6). It is quite clear that we are, and will be, seeing more substantial attempts at utilizing waste materials, including waste heat in beneficial ways, especially in aquaculture (Mihursky, 1970). However, as Nash (1970) has cautioned, aquaculture not only needs the benefits of strain selection, advanced nutritional knowledge, hybridization

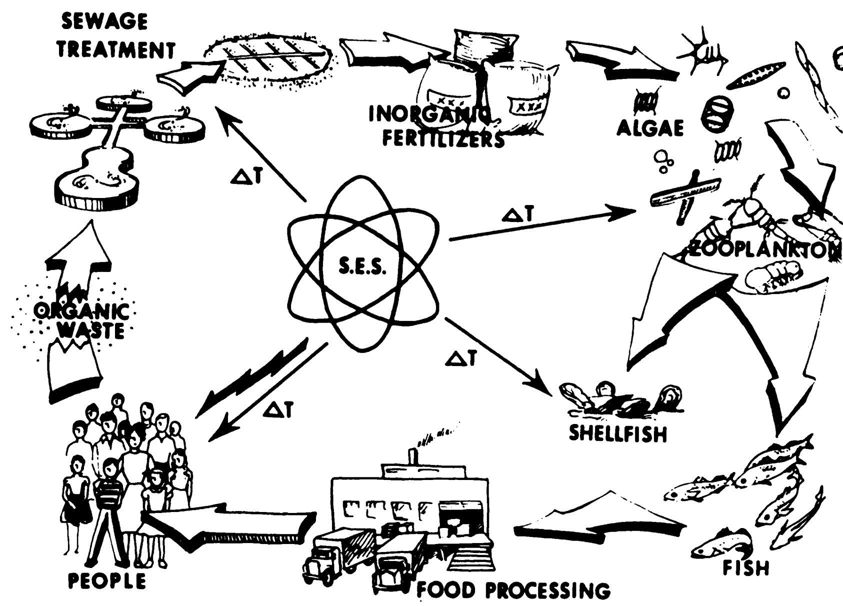

FIGURE 6. *A schematic representation of a closed cycle utilizing waste heat to produce protein. The waste heat released from power plants is used successively to accelerate bacterial decomposition of sewage, to maximize algal and zooplankton growth which may be fed to shellfish or aquatic vertebrates, and possibly to heat homes, etc. The biomass produced with the aid of waste heat is cycled to human utilization.*

and lineage, but also needs much more information on disease control and medication. These latter needs are especially critical under the crowded conditions found in intensive aquaculture. The bulk of our knowledge in this problem area has come from traditional hatchery type operations such as found here in the United States with salmonid fishes. It seems certain that many new species will be utilized in future recycling systems and many new host-disease relationships will have to be understood.

In summary, it is quite clear that sub-optimal environmental conditions, although recognized by researchers, have not been easily defined and documented from an ecological approach. It is these difficult to identify and measure, sub-optimal conditions that are undoubtedly causing population extirpation and extinction. It is also obvious that there will be an increase in man-caused environmental modifications in both natural open systems and in artificial closed aquaculture systems. The need to understand the limitations of these environments and to properly control them, dictate that pathobiologists will be forced into greater service, as this discipline seems to have the potential for playing a strong future role in understanding the ecological problems of environmental modifications.

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