The Potential of Pollutants To Adversely Affect Aquaculture

WILLIAM E. ODUM
Department of Environmental Sciences
University of Virginia
Charlottesville, Virginia 22903

INTRODUCTION

The purpose of this report is to examine the potential of pollutants to act as limiting factors on aquaculture. Judging from the lack of documented cases, this has not been a serious problem in the past. Apparently, this stems from a negative correlation between industrial development and aquaculture development: Those sections of the world that have seen the greatest industrial advancement have not developed extensively in terms of aquaculture. One of the exceptions to this general pattern is Japan which, significantly, has experienced serious interactions between industrial polluters and culture and inshore fishery operations (e.g., reduced production from pearl oyster rafts anchored in polluted waters and the Minamata Bay disaster.)

Before discussing specific types of pollutants, it is useful to make two points:

(1) INTENSIVE VERSUS EXTENSIVE AQUACULTURE

As the world becomes more highly developed industrially, the amount of damage to aquaculture from pollution will be related to the degree of control exercised by the aquaculturist over his operation. Considered as a compartment, the aquaculture facility has three major inputs – one from the atmosphere, one from land drainage and one from the water source. In an extensive (open) operation, such as the raising of fish in a large lagoon blocked off with netting, little or no control is possible over any of these inputs. In an intensive (closed) operation, such as a pond, control is possible over everything except the atmospheric input. In some theoretical plans, such as bottle culture of trout and rearing of shrimp in individual plastic cells, complete control is possible. This assumes, of course, that continual monitoring of incoming water can be performed routinely. In the future, one way that aquaculture may continue to flourish in certain highly developed countries may be through the use of sophisticated, intensive methods.

(2) DECREASED ECOLOGICAL STABILITY

Because aquaculture is maintained at elevated net production levels through the use of external energy subsidies, aquaculture facilities ecologically are highly unstable and much more easily perturbed than a natural ecosystem (see Fig. 1). The concept of ecological stability is used here as defined by Hurd *et al* (1971) as the ability of a system to maintain or return to its ground state after an external perturbation.

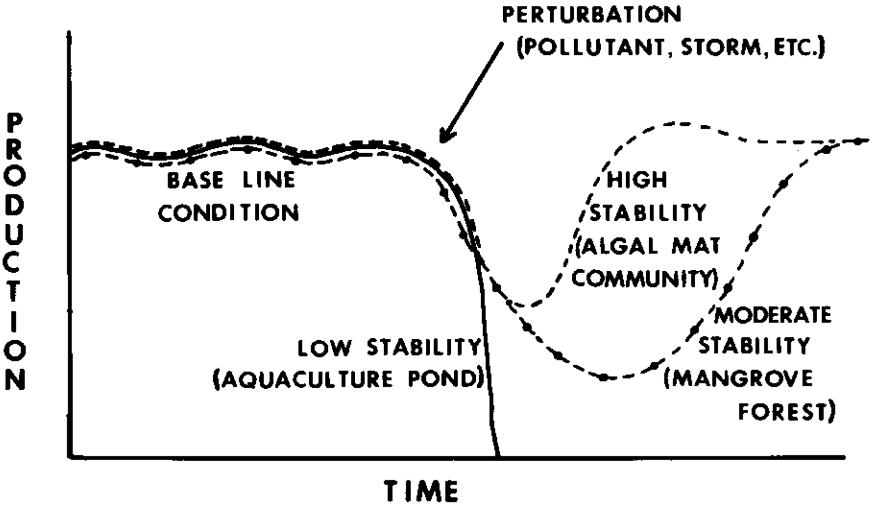

Fig. 1. Hypothetical representation of three responses to an external pertubation. Note the considerable damage but rapid recovery of the high stability system, the greater damage and slower recovery of the moderate stability system and the complete collapse of the artificial culture system. In the latter case, production may eventually recover, but in an entirely different form from the original condition. For instance, once a shrimp or pompano population has been destroyed, natural mechanisms will not recreate the original condition.

This lowered ecological stability is reflected both by the entire system and the populations of culture organisms within. This means that diseases, parasites and levels of lowered oxygen or increased pollutants that would have little effect on a population in its natural environment may limit growth or even prove fatal in the extreme conditions of an aquaculture pond. It also means that synergistic effects of crowding, such as those created by high nutrient levels, elevated temperatures and pollutants working together, may create results that could not be foreseen from experience or experiments in the natural environment. As an example, Pringle *et al* (1968) have shown that in a "simulated natural environment," multiple factors such as temperature, time of exposure and the physiological activity can combine to increase the rate of heavy metal uptake by shellfish. This may explain why Galtsoff *et al* (1947) found oysters near a paper mill effluent reacting to the stressful environment by concentrating copper at abnormally high levels even though the effluent contained no increased copper concentration.

ORGANIC WASTES AS POLLUTANTS

Included in this category are animal waste products and other naturally occurring organic materials. These are biodegradable substances for which there exist naturally evolved mechanisms which, if not overloaded, take care of treatment by decomposition. Generally, these compounds are non-toxic (note the exception of certain petroleum by-products) and at low to moderate concentrations may stimulate production.

The beneficial effects of limited biodegradable pollution have been recognized for centuries and incorporated into traditional aquaculture practice (discussed by Hickling, 1970). These included the judicial addition to ponds of human and animal wastes along with many types of organic matter – leaves, wood and portions of agricultural plants.

At higher concentrations, adverse effects begin to appear, but these are often difficult to recognize because they are usually manifested in an indirect manner. Potential problems for aquaculture include: (1) LOWERED DISSOLVED OXYGEN CONCENTRATIONS – at high concentrations of organic matter, the demand for oxygen from chemical and microbial decomposition becomes so great that the oxygen concentration in the water may be lowered disastrously. This is a common problem for pond culturists who have intentionally or unintentionally allowed too much organic matter to enter their ponds. Usually, large die-offs of culture species due to reduced oxygen concentrations occur at night when plant respiration is added to microbial demands. Mechanisms commonly employed to prevent depletion involve aeration of the water with devices such as fountains and water wheels. (2) UNWANTED INCREASES IN PRIMARY PRODUCTION – elevated nutrient levels accompanying high concentrations of organic input can encourage plant forms that are useless to the herbivores under culture and may further lower oxygen concentrations during the night. (3) INCREASED TURBIDITY – when large concentrations of fine, particulate organic detritus are added to a pond or stirred up from the bottom sediments they may interfere with light transmission. The nutrients accompanying organic additions to a pond may cause phytoplankton blooms, which also increase turbidity. In either case primary production is limited by the lower light levels and the result may be a large scale death of algae and lowered oxygen levels. (4) LOWERED PH – humic acids derived from excess amounts of organic matter decaying within a pond or its watershed are capable of lowering the pH to a point where production is adversely affected. This is a particularly serious problem in stagnant ponds with low flushing rates. Problems have been encountered in the Philippines in situations in which mangrove swamps drain into large ponds with restricted flushing and high evaporation rates (Heald, personal communication). A pH of 5 or below seems to seriously inhibit both plant and fish growth. If the pond has a carbonate sediment bottom, the pH remains at a higher level.

CASE HISTORY

One of the best documented and most quoted cases of alteration of a culture operation is that associated with the expansion of duck farms adjoining the oyster fisheries of Moriches Bay and Great South Bay, Long Island, New York (Ryther, 1954; Barlow *et al,* 1963; Galtsoff, 1956). Organic matter and nutrients originating from untreated wastes from these duck farms completely altered the ecological characteristics of the two embayments into which the effluents emptied. The most striking effect was a change in the types of dominant phytoplankton present. Unfortunately, the forms of phytoplankton encouraged by the eutrophicated conditions were not suitable for oyster growth, and oyster production declined.

HEALTH HAZARDS FROM THE USE OF SEWAGE

Examples of damage to aquaculture from untreated sewage are numerous. These have been especially serious in the culture of filter-feeders such as oysters and clams, which may not be noticeably affected but are capable of concentrating bacteria and viruses harmful to man (discussed by Paoletti, 1965). Attempts to use treated sewage as a nutrient source for aquaculture should be accompanied by precautions to insure that the treated sewage is free of harmful microorganisms.

CHLORINATED SEWAGE EFFLUENTS

If the sewage is treated with chlorine, further precautions should be taken to insure that the effluent is free of chlorine before being dumped into cultural ponds. Tsai (1968) has shown detrimental effects of chlorinated sewage effluents immediately below sewage outfalls. These include lowered species diversity and abundance of fishes even though oxygen and pH were normal. On the other hand, Rickards (personal communication) encountered no difficulties in using sewage effluents treated with low levels of chlorine in aquaculture ponds at Morehead City, North Carolina.

One way to avoid this problem, if it exists, would be to replace chlorine treatment with ozone treatment. Although slightly more expensive, this method produces no harmful contaminant in the effluent.

INDUSTRIAL WASTES

Substances such as long-chain phenolic chemicals, ammonium salts, cyanides, sulfates, nitrates and heavy metals are common to industrial wastes and pose a threat to aquaculture facilities in the vicinity of industrial outfalls. In contrast to organic wastes, these are nondegradable pollutants that either degrade very slowly or do not degrade at all. The toxicity of these substances to fish and aquatic invertebrates has been firmly established (see Jones, 1966; Anon., 1968). Any significant addition of these compounds to the environment or to an aquaculture operation will result in lowered secondary production. Potentially more serious is the tendency of many organisms and especially filter feeders to concentrate and store copper, mercury, lead and arsenic at levels that may be dangerous for the consumer.

MINAMATA BAY

The disaster associated with Japan's Minamata Bay (Irukayama, 1966) demonstrates the potential of industrial effluents to severely disrupt inshore fisheries and aquaculture. This problem originated from a plastics factory that produced vinyl chloride with the use of a mercury catalyst. From 1948 to 1960 this factory dumped in excess of 300 grams of methyl mercury daily into the bay. The mercury was quickly taken up by the sediments and then by fish and shellfish. Between 1953-1960 large numbers of people who ate these organisms became seriously ill and 46 died. A similar disaster occurred at Nigata in 1965, resulting in 120 stricken and five deaths.

Although conventional fisheries were most seriously affected, both cases demonstrate the potential for an industrial pollutant to seriously upset the operation of an aquaculture facility at some distance from the source.

PETROLEUM PRODUCTS

Extensive aquaculture (open systems) in the vicinity of heavy shipping or oil refineries may suffer damage from oil pollution. Iversen (1968) mentions several instances of oyster farms in Puget Sound, Washington, which experienced extensive damage from nearby oil spills.

Evidently, molluscs are more susceptible to direct mortality from petroleum products than are fishes (Nelson-Smith, 1970). This is because the outer surface of fish, their mouths and gill-chambers are coated with a slimy oil-repellent mucous. Steed and Copeland (1967) have shown, however, that low concentrations may stress fish and other organisms to the point that growth is curtailed, and the organism becomes more susceptible to other stresses such as lowered oxygen. Lower concentrations that do not noticeably affect the metabolism may cause the flesh to have an undesirable flavor. Mann (1965) has implicated low concentrations of phenolic compounds, tar derivatives and mineral oils as responsible for unappetizing flavors in fish. As little as 0.01 parts per million (ppm) oil can give rise to a marked taste in the oyster, *Crassostrea virginica,* and after heavier doses the offensive flavor may persist for 6 months (Menzel, 1948).

PESTICIDES

The problems associated with the intentional or accidental introduction of pesticides into estuaries have been reviewed by Butler (1966) and Johnson (1968). The types of adverse effects encountered by the aquaculturist include loss of production, ill-defined but significant mortality and sub-lethal effects such as lowered resistance to disease, behavioral and feeding difficulties and poor reproduction.

McLarney (1970) has cited specific cases of pesticide damage to aquaculture. In one instance, a bait minnow farmer in Arkansas attempted to convert 115 acres of cotton fields into fish ponds, but failed completely because of concentrations of endrin and dieldrin that had accumulated in the soil. He also points out the dangers to the catfish industry of high non-lethal levels in their final product. Wild catfish have been caught with DDT levels as high as 58 ppm, 10 times the amount allowed by the U.S. Food and Drug Administration.

In southeast Asia, fish kills are more frequent in rice paddy aquaculture because of increased pesticide usage to protect the "Green revolution" (Hinckley, personal communication). As a result, the protein intake of the peasant population has been lowered.

INPUT VIA FOOD SUPPLEMENTS

In most cases, pesticides enter culture ponds from the atmosphere or water supply. Stober and Payne (1966) have shown an additional source – commercial fish food pellets. Analysis of several commercially available pelleted fish foods revealed chlorinated hydrocarbons at low parts per billion levels. Routine consumption of this food could lead to unacceptable concentrations in the culture species. An even more serious problem has been mentioned by Bookout (in press). Brine shrimp originating from Salt Lake, Utah, and used to rear larval culture organisms had such high pesticide levels that they caused extensive larval mortality.

EFFLUENTS FROM POWER STATIONS

EFFECTS OF HEATED EFFLUENTS

Detrimental effects to properly located aquaculture facilities from heated water should be minimal and heavily outweighed by beneficial effects, including increased growth rates. It should be remembered, however, that a rise in water temperature often increases the susceptibility of organisms in a synergistic manner to toxic materials, disease or parasites.

ISOTOPES

The effluent from nuclear power plants is not regarded as a likely source of serious environmental contaminants. This is because levels of stable elements (Cl, Cu, etc.) and radioisotopes in the discharge waters are generally low and are further diluted when dumped into natural bodies of water. Preston (1968) has confirmed this assumption for nuclides after monitoring shellfish in the region of existing nuclear stations in Britain.

One possible exception to this assumption concerns the proposed culturing of organisms such as shrimp, oysters and catfish (Yee, 1972) directly in the warm, undiluted effluent adjacent to the power station. Such practices could lead to problems, particularly for organisms such as oysters, which are capable of concentrating nuclides at levels thousands of times greater than in the water in which they are found. The phenomenon of uptake and bioaccumulation of radioisotopes through aquatic foodchains has been discussed by a number of authors (see Davis and Foster, 1958; Aberg and Hungate [eds.], 1966; Wolfe, 1969). In addition, many organisms, including oysters, have the ability to absorb zinc and other elements directly from the water across active membranes such as gill tissue.

CASE HISTORY: HUMBOLDT BAY POWER PLANT

To test the possibility of bioaccumulation in reactor effluents, Salo and Leet (1967) suspended trays of Pacific oysters, *Crassostrea gigas,* in the discharge canal of the Humboldt Bay Power Plant near Eureka, California. The oysters were maintained for over 400 days and sampled periodically.

This plant is typical in that low-level wastes are collected routinely and discharged periodically into the effluent. These wastes accumulate during normal operation from reactor water, steam system drainage, floor drainage of the radiation zone, liquids associated with fuel handling, fuel storage basins, the radiochemical laboratory, the laundry room, from equipment decontamination activities and from routine maintenance operation. Prior to discharge, the wastes are stored in holding tanks where they undergo radioactive decay until necessary standards can be met.

Samples of discharge water from the plant during the period of January 1965 up to June 1966 revealed significant amounts of induced nuclides: ^{65}Zn, ^{54}Mn, ^{59}Fe, ^{51}Cr and ^{60}Co. Eighty-seven percent of total activity was due to ^{65}Zn. After February 1966 ^{137}Cs and ^{134}Cs resulting from defective fuel cladding were present in the discharge water as well as induced nuclides.

During the 13-month period of the experiment, ^{65}Zn concentration in the water ranged from 0.104×10^{-2} pCi/ml to 1.963×10^{-2} pCi/ml; the variation reflected the amounts of stored wastes added to the discharge. The concentration in oyster meats reflected these changes in the discharge water and ranged from 0.99 pCi/g to 174 pCi/g.

Even though the levels in the oyster meat represented a concentration factor of 5000 to 10,000, the maximum concentration of 174 pCi/g was not judged to be dangerous. The authors concluded that the maximum body burden that a human would derive from a protein diet consisting of these oysters would be well within maximum permissible concentrations.

A similar oyster cultivation study was conducted in the discharge water of the Bradwell Nuclear Station in Great Britain (Preston, 1967). Interestingly, the concentrations of radionuclides accumulated by oysters in this discharge canal were in the same range as the Humboldt Bay oysters.

THE DELANEY CLAUSE

At the present time, any consideration of aquaculture in nuclear power plant effluents is rendered virtually impossible by the Delaney Clause of the Federal Food, Drug and Cosmetic Act [sec. 409 (C) (3)(A)]. This amendment stipulates the removal from interstate commerce of any food that contains analytically detectable amounts of a food additive shown to be capable of inducing cancer in experimental animals when given in very high doses. Clearly, this 20 year-old clause should be modified for certain situations. Refined research equipment has redefined "analytically detectable" by several orders of magnitude, and extensive research has shown that many contaminants are harmless when present at low concentrations.

COPPER

A number of papers have demonstrated the ability of organisms, particularly oysters, to concentrate stable copper at high levels from water low in copper (summarized by Roosenburg, 1969). The toxicity of copper in oysters to humans has been reported by O'Shaughnessy (1966) and Chang (1962). Since increased concentrations of copper are often present in power plant effluents, presumably originating from condenser tubes, it might be good to take a closer look at this potential problem.

CASE HISTORY: CHALK POINT POWER PLANT, MARYLAND

Roosenburg (1969) has studied the concentration of copper in oysters (*Crassostrea virginica*) in the Patuxent River estuary downstream from the Chalk Point, Maryland, steam electric generating station. The condenser tubes in this plant were originally stainless steel, but rapid erosion caused their replacement with aluminum-bronze tubes and finally copper-nickel tubes.

Shortly after initiation of plant operations, oyster meats near the outfall of the plant displayed a green color and high copper concentrations. With time, high copper concentrations spread to oysters further downstream. Copper content of oysters decreased with distance from the outfall.

It was concluded that erosion of copper from condenser tubes alone may not have been responsible for increased concentrations in oysters. Other factors such as increased temperature stress along with low levels of chlorine may have interacted to produce the phenomenon. Whatever the cause, the implications are serious to anyone wishing to grow oysters in power plant effluents. Green coloration, a bitter taste and possible toxicity from copper would render the oysters unfit for consumption.

CHEMICALS FOR THE PREVENTION OF FOULING

Chemicals for the prevention of fouling pose a serious problem to the aquaculturist attempting to utilize undiluted heated discharges. For example, continual low levels of chlorine are used by many generating stations as a treatment for prevention of condenser slimes and fouling organisms. Ansell (1969) has mentioned that low levels of chlorine residues remaining in the discharge water are effective in reducing growth in the mussel, *Mytilus edulis*, and the clam, *Mercenaria*.

That chlorine can be present at relatively high concentrations at some distance from reactor outfalls is emphasized by Carter's (1968) inability to use dye tracers to follow discharges from the Chalk Point Plant due to interference of chlorine residues with the dye.

A FINAL POINT

Not only pollutants but also large scale modifications of the environment such as water diversion, dredging and filling all have the potential to disrupt aquaculture facilities. For instance, Cronin (1967) discusses the effects of the Bonnet Carre Spillway, which diverts flood waters from the Mississippi River through Lake Pontchartrain and eventually the Gulf of Mexico. Effects on oyster culture in the Lake were mixed. Beneficial results include nutrient addition of 40,000 tons/year and reduction of oyster predators due to lowered salinity. Detriment to the oysters stemmed from increased siltation on oyster beds. Although Gunter (1953) concluded that the total beneficial economic effect outweighed the partial oyster mortality, in other situations the outcome might not be so favorable.

LOSS OF ESTUARINE LAND

Hickling (1970) makes the point that the future of estuarine aquaculture is linked with the fate of the estuaries themselves. In rapidly developing countries such as the United States, this is a serious problem. For example, Schmidt (1966) calculated that 47,000 acres of marsh between Maine and Delaware have been lost since 1954. The cause of these losses include: dumping of soil, 34%;

bridges, roads, airports and parking facilities, 27%; housing developments, 15%; industrial sites and trash dumps, 10%; recreation facilities, 13%; schools, agricultural croplands, drainage and beach erosion controls, 1%. All of these uses compete directly with aquaculture for the limited space available.

SUMMARY

(1) Documented cases of damage to aquaculture from pollution are rare.

(2) Intensive (closed) operations should have greater control over the introduction of pollutants than extensive (open) facilities.

(3) Aquaculture ponds are ecologically unstable and more easily perturbed than natural ecosystems.

(4) Deleterious effects of organic wastes are usually manifested in an indirect manner – lowered oxygen concentrations, lowered pH and/or increased turbidity.

(5) Minamata Bay is presented as the type of problem that may arise from pollution of aquaculture from industrial wastes.

(6) Petroleum products may affect survival, growth and taste of culture organisms depending upon the concentration of the pollutant.

(7) Pesticides may be introduced by way of pelleted foods.

(8) The danger of bioaccumulation of isotopes in nuclear power plant effluents is discussed and discounted.

(9) Copper and chlorine may be serious contaminants in power plant aquaculture.

REFERENCES

Aberg, B. and F. P. Hungate (Eds.)
1966. Radioecological concentration processes. Proc. Intern. Symp. Stockholm. Pergamon Press, London, 1040 pp.

Anonymous.
1968. Water quality criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior, Washington, D.C.

Ansell, A. D.
1969. Thermal releases and shellfish culture: possibilities and limitations. Ches. Sci. *10*(3-4):256-257.

Barlow, J. P., C. J. Lorenzen and R. T. Myren.
1963. Eutrophication of a tropical estuary. Limnol. and Oceanog. *8*(2):251-262.

Butler, P. A.
1966. The problem of pesticides in estuaries. *In* A Symposium on estuarine fisheries. Am. Fish. Soc. Spec. Pub. 3:110-116.

Carter, H. H.
1968. The distribution of excess temperature from a heated discharge in an estuary. Ches. Bay Inst. Tech. Rept. 44 Ref. 68-14. The Johns Hopkins University.

Chang, P. S.
1962. Effects on oysters and fish in Taiwan. Third Seminar in Biological Problems in Water Pollution. USDHEW: Public Health Service Publication No. 999-WP-25:368-369.

Cronin, L. E.
1967. The role of man in estuarine processes. *In* Estuaries, G. Lauff (ed.), Pub. by Amer. Assoc. Adv. Sci.: 667-689.

Davis, J. J. and R. F. Foster
1958. Bioaccumulation of radioisotopes through aquatic food chains. Ecology *39*(3):530-535.

Galtsoff, P. S.
1956. Ecological changes affecting the productivity of oyster grounds. N. Amer. Wildl. Conf. Trans. *21*:408-419.

Galtsoff, P. S., W. E. Chipman, Jr.,
J. B. Engle and H. N. Calderwood.
1947. Ecological and physiological studies of the effect of sulfate pulp mill wastes on oysters in the York River, Virginia. U. S. Fish Wildl. Serv. Fish Bull. *43*(vol 51):50-186.

Gunter, G.
1953. The relationship of the Bonnet Carré Spillway to oyster beds in Mississippi Sound and the "Louisiana Marsh" with a report on the 1950 opening. Univ. Texas Publ. Inst. Marine Sci., *3*(1):17-71.

Hickling, C. F.
1970. Estuarine fish farming. Advances in Mar. Biol. *8*:119-214.

Hurd, L. E., M. V. Mellinger, L. L. Wolf
and S. J. McNaughton.
1971. Stability and diversity at three trophic levels in terrestrial successional ecosystems. Science *173*(4002):1134-1136.

Irukayama, K.
1966. The pollution of Minamata Bay and Minamata disease. Adv. Water Pollution Res. *3*:153-165.

Iversen, E.
1968. Farming the Edge of the Sea. Fishing News (Books) Ltd., London, 301 pp.

Johnson, D. W.
1968. Pesticides and fishes – a review of selected literature. J. Am. Fish. Soc. *97*(4):398-424.

Jones, J. R. E.
1966. Fish and river pollution. Butterworth & Co., Ltd.

McLarney, W. O.
1970. Pesticides and aquaculture: a scientist's plea for ecological sanity. Am. Fish. Farmer, Sept.:6-7.

Mann, H.
1965. Effects on the flavor of fishes by oils and phenos. Comm. Int. L'Explor. Sci. de la Mer Mediterranee, Monaco:371-374.

Menzel, R. W.
1948. Report on two cases of oily tasting oysters at Bay Sainte Elaine oilfield. Texas A & M Research Foundation.

Nelson-Smith
1970. The problem of oil pollution of the sea. Advances in Mar. Biol. *8*:215-306.

Odum, E. P.
1971. Fundamentals of Ecology, Third edition. W. Saunders Publishing Co., Philadelphia, Penn.

O'Shaughnessy, A. W. E.
1966. On green oysters. Ann. Mag. Nat. Hist. 3rd Series. *18*:221-228.

Paoletti, A.
1965. Hygienic problems of shellfish. Comm. Int. L'Explor. Sci. de la Mer Mediterranee, Monaco:251-264.

Preston, A.
1967. A concentration of zinc-65 in the flesh of oysters related to the discharge of cooling pond effluent from the CEGB nuclear power station at Bradwell-on-Sea, Essex. In B. Aberg and F. P. Hungate (editors), Radioecological Concentration Processes. Pergamon Press, Oxford, p. 995-1004.

Preston, A.
1968. The control of radioactive pollution in a North Sea oyster fishery. Helgolander wiss. Meeresunters *17*:269-279.

Pringle, B. H., D. E. Hissong, E. L. Katz and S. T. Mulawka
1968. Trace metal accumulation by estuarine mollusks. Proc. Amer. Soc. Civ. Eng. *94*(SA3):455-475.

Roosenburg, W. H.
1969. Greening and copper accumulation in the American oyster, *Crassostrea virginica,* in the vicinity of a steam electric generating station. Ches. Sci. *10*(3&4):241-252.

Ryther, J. H.
1954. The ecology of phytoplankton blooms in Moriches Bay and Great South Bay, Long Island, N. Y. Biol. Bull. *106:*198-209.

Salo, E. O. and W. L. Leet
1967. The concentration of ^{65}Zn by oysters maintained in the discharge canal of a nuclear power plant. Proc. 2nd Nat. Symp. on Radioecology, p. 363-370.

Schmidt, R.
1966. Needed – a coastwide comprehensive program for development of estuaries. Supplement to Trans. Amer. Fish. Soc. *95*(4):102-109.

Steed, D. L. and B. J. Copeland
1967. Metabolic responses of some estuarine organisms to an industrial effluent. Univ. Texas Cont. Marine Sci. *12:*143-149.

Stober, Q. J. and W. R. Payne
1966. A method for preparation of pesticide-free fish food from commercial fish food pellets. Trans. Am. Fish Soc. *95*(2):212-214.

Tang, Y. A. and S. Chen.
1966. A survey of the algal pastures of milkfish ponds in Taiwan. FAO World Symposium on Warm-water Fish Culture. Rome.

Tsai, C.
1968. Effects of chlorinated sewage effluents on fishes in upper Patuxent River, Maryland. Ches. Sci. *9*(2):83-93.

Wolfe, D. A.
1969. Ecosystems stressed by additions of man-made radioactivity. *In* Coastal Ecol. Systems of the U. S. Rept. to F.W.P.C.A.: p.1304–1330. (In press – U. S. Printing Office).

Yee, W. C.
1972. Thermal aquaculture: engineering and economics. Environ. Sci. and Tech. *6*(3):232-237.