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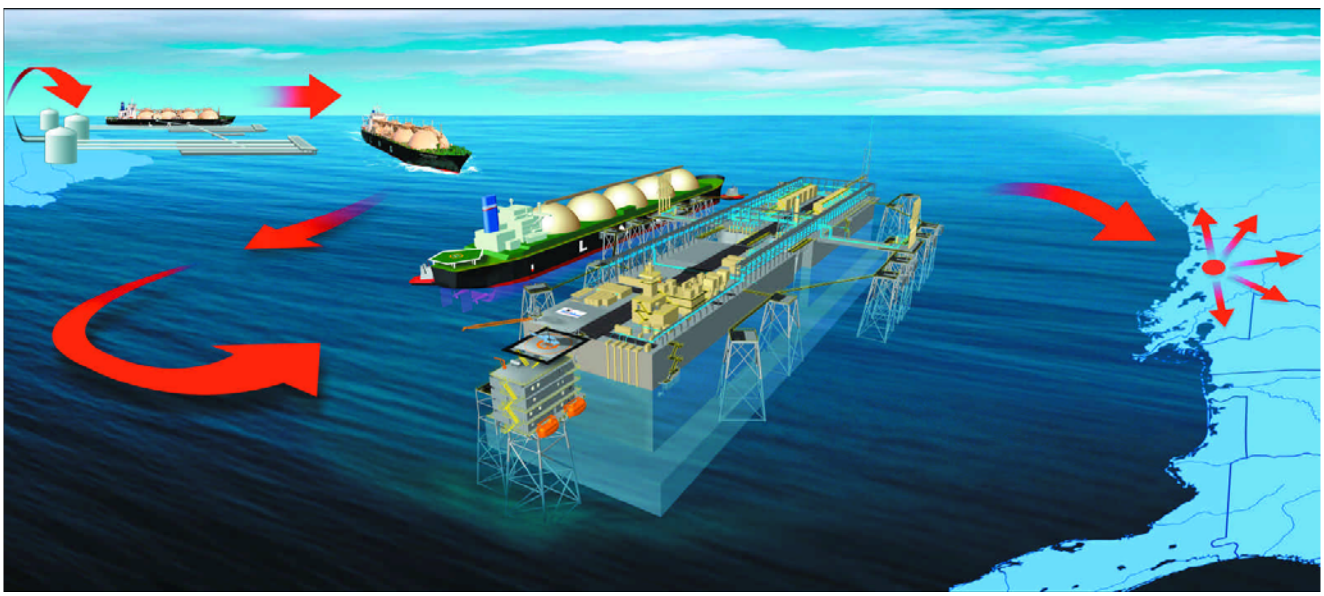
MMS 2006-071

Coastal Marine Institute

Annotated Bibliography of the Potential Environmental Impacts of Chlorination and Disinfection Byproducts Relevant to Offshore Liquefied Natural Gas Port Facilities



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

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

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ABOUT THE COVER

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INTRODUCTION

This research specifically addresses a Minerals Management Service (MMS) “Special Task Area” and also responds to urgent informational needs of the Environmental Protection Agency, the U.S. Coast Guard, NOAA’s National Marine Fisheries Service (NOAA NMFS), and northern Gulf of Mexico state natural resource agencies. We conducted an extensive literature search and compiled an indexed, annotated bibliography on the toxicity of intake chlorinated waters and their disinfection byproducts associated with proposed offshore, open-loop (flow-through), Liquefied Natural Gasification (LNG) terminals and the potential environmental consequences that will result when these substances are discharged into the marine environment.

Consideration of the application and licensing of these offshore LNG facilities with open-loop, intake water circulation systems is on-going. Environmental concerns still remain within the regulatory oversight agencies, the commercial and recreational fishing industries, and with the public-at-large. These concerns have specifically focused on the anticipated accumulative high mortalities of commercially- and recreationally-important ichthyoplankton and zooplankton (i.e., decapods or crabs and shrimp). These mortalities will result from the impingement, entrainment, toxic exposure to chlorination and disinfection byproducts (DBPs) associated with treatment of intake waters, and from cold shock during the operation of these proposed LNG open-loop systems.

BACKGROUND AND MOTIVATION

On November 25, 2002, Congress amended the Deepwater Port Act of 1974 (DWPA) by passing Section 106 of the Maritime Transportation Security Act. Section 106 made the following licensing and regulatory responsibility changes: 1) It redefined, under the DWPA, the Secretary of Transportation's authorization to issue licenses to own, construct, and operate deepwater ports (i.e., floating or man-made structure other than vessels in federal waters) for the purposes of storing, transporting, or handling oil, to also include natural gas; and 2) It transferred oversight of offshore natural gas terminals from the Federal Energy Regulatory Commission to the Maritime Administration (MARAD) with the Department of Transportation (DOT) and the U.S. Coast Guard (USCG now in the Department of Homeland Security having moved from DOT). To date, the USCG has received 14 applications for Deepwater Port Licenses for proposed Liquefied Natural Gas (LNG) Terminals in the northern Gulf of Mexico. As presently proposed, all but two of these offshore, "platform"/port facilities will need very large volumes of subsurface seawater (probably taken from a staggered array of intake ports located between 10-30m depth) to warm and re-gasify the LNG. These ambient waters which will be chlorinated and subsequently chilled will then have to be discharged back into the marine environment, probably through a turbulent diffuser system. Since these proposed LNG facilities will utilize such an "open-loop" warming system, the various regulatory agencies involved have expressed concerns about possible effects associated with this technology. Namely, that the accumulated impacts of impingement on intake screens and entrainment within the chlorinated and chilled processed waters within these systems may result in significant adverse effects on the early life history stages of fish and decapods and their subsequent adult populations especially for managed species along the AL-MS-LA-TX continental shelf.

On February 16, 2005, MARAD's most recent open-loop decision was handed down granting Shell U.S. Gas and Power's license to operate the Gulf Landing LNG terminal in West Cameron Block 213, 38 statute miles off Cameron, LA. The terminal will be capable of processing 1 billion cubic feet of gas per day, necessitating that more than 136 million gallons of sea water per day be pumped through its radiator-like system. Two other licenses have been granted: ChevronTexaco (Port Pelican, 36 miles off southwest LA-Vermilion Block 140, first to receive a license on March 31, 2004, for a 176 million gal/day facility); and Excelerate Energy (Gulf Gateway Energy Bridge Deepwater Port, a submersible buoy 116 miles off Cameron, LA, in 91 meters of water, which requires a ship that can regasify the LNG onboard under a license to operate at a peak volume of 76 million gal/day of seawater for 248 days/year) which is now operational (March 20, 2005) and has already offloaded three shipments of LNG. There are presently two (2) other LNG open-loop terminals proposed for the north-central Gulf, i.e., Conoco-Phillips (Beacon Port Clean Energy Terminal, High Island Block 71, 56 miles off the LA-TX border – presently under review); and Torp Technology's Bienville LNG Offshore Energy Terminal, BOET (Main Pass Block 258, 63 miles south of Mobile Point, AL). Freeport McMoRan Main Pass Energy Hub (Main Pass Block 299, 37 miles east of Venice, LA) recently received (January 3, 2007) approval of its application, which it had amended proposing a closed rack system that will use very little ambient seawater.

Finally, both ExxonMobil (Pearl Crossing, 41 miles SE of Cameron) and Conoco-Phillips (Compass Point, 11 miles off Dauphin Island, AL) have withdrawn their open-loop applications.

Therefore, to meet the information needs of MMS, EPA, USCG, NMFS/NOAA and state regulatory agencies, we have provided an annotated bibliography on reported research concerning the affects of chlorinated marine waters and their resultant DBPs in water intake and discharge systems, especially as they relate to marine and estuarine ichthyoplankton and zooplankton likely to be entrained within the intake waters of offshore LNG port facilities.

METHODOLOGY

We have conducted an on-line search of all potentially-relevant databases and then compiled an annotated bibliography, based upon the pertinent literature, i.e., peer-reviewed and non-peer-reviewed literature as well as the "grey literature" (e.g., government documents, conference proceedings, major technical reports, etc.) relevant to coastal/marine pelagic communities within the northcentral Gulf of Mexico. We focused particularly on the effects of chlorinated waters and associated DBPs and their influence on larval/juvenile fishes and commercially- or recreationally-important invertebrates (i.e., decapods or shrimp and crabs).

The criteria used to determine whether a reference might be useful or not had to be adjusted as the search progressed. Only references related to the effects of chlorination, resultant DBPs or chlorinated water discharge on the affected species or on the chemical composition of the receiving marine and estuarine environments were selected. No consideration was given for other closely related topics, such as fish impingement or entrainment associated with open-loop or flow-through water systems, which may have been covered elsewhere (e.g., Martinez-Andrade, F. and D.M. Baltz. 2003. Marine and coastal fishes subject to impingement by cooling-water intake systems in the northern Gulf of Mexico: An annotated bibliography. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-040. 113 pp.).

The search strategy included preparation of initial keyword and database lists. All data bases available for searching in the library at Louisiana State University and relevant to aquatic Biology were queried to search article titles, abstracts, keyword lists, and any other available text in the databases using the list of key words. Eleven key words or phrases, root forms, and logical operators (e.g., AND & OR) were used to develop the bibliography (see below List of Keywords Searched). This search captured documents from 1964 to May 2006.

Several thousand documents were found using this initial method of searching through the selected databases. During several subsequent screening and review processes, close to 200 documents were finally selected for inclusion into the finished work. Some data bases, especially those dealing with the grey literature or those citations before 1980, did not provide abstracts.

Finally, each selected article was categorized and cross-referenced by subject matter. A subject index of these categories was created which points the user of the bibliography to the appropriate articles on the subjects by listing the authors and year of publication for each article under the subject heading. A genus species index, which points the user to articles that treat the taxa listed, was also created in this manner.

LIST OF KEYWORDS SEARCHED

chlorination
disinfection byproducts
intake water
discharge water
cooling water
heating water
entrainment
power plant
ichthyoplankton
zooplankton
marine organisms

ANNOTATED BIBLIOGRAPHY

Abarnou, A. and L. Miossec. 1992. Chlorinated waters discharged to the marine environment chemistry and environmental impact: An overview. Science Total Environment 126(1-2): 173-197.

Chlorinated discharges into coastal waters are of great environmental concern because of the large amount of chlorine and the diversity of the compounds involved. Seawater chlorination for cooling systems and disinfection of urban wastewaters are the major sources of these hazardous compounds reaching the marine environment. Seawater chlorination (at the mg/L level) produces bromine which disappears rapidly in receiving waters yielding organobrominated compounds. Chlorination of urban wastewaters, containing high concentrations of organic carbon and ammonia, requires higher chlorine dosage (5-20 mg/L) to fulfill the disinfection requirements. Monochloramine still active is the predominant final compound. Organochlorinated by-products represent a minor part of the added compound; however they need further investigations to precisely evaluate their potential hazard to marine life because of their persistence and mutagenic character.

Ahamed, M.S., K. Suresh, G. Durairaj and K.V.K. Nair. 1993. Effect of cooling water chlorination on primary productivity of entrained phytoplankton at Kalpakkam, east coast of India. Hydrobiologia 271(3): 165-168.

We studied the effect of various concentrations of chlorine, used in the cooling system of Madras Atomic Power Station (MAPS), on the primary productivity of entrained phytoplankton from October 1988 to December 1990. The rates of primary productivity (gross) were lower at the discharge point than in the intake area. The reduction in productivity ranged from 30 to 70% at low-dose chlorination (residual chlorine 0.05-0.20 mg/L at the discharge point). During shock-dose chlorination, when residual chlorine at the discharge point ranged from 1.10 to 1.50 mg/L, the reduction in productivity was 80-83%. A reduction of 16-17% was recorded without chlorination.

Alderson, R. 1969. The survival of flatfish eggs, larvae, and post-larvae in low concentrations of free chlorine. Report No. ICES 27, International Council for the Exploration of the Sea, Port Erin, United Kingdom.

No abstract.

Alderson, R. 1972. The effects of low concentrations of free chlorine on eggs and larvae of plaice, *Pleuronectes platessa* L. Pp. 312-315. In: M. Ruvio (ed). Marine Pollution and Sea Life. Fishing News Books Ltd., Surrey, England.

No abstract.

Alderson, R. 1974. Sea-water chlorination and the survival and growth of the early developmental stages of plaice, *Pleuronectes platessa* L, and Dover sole, *Solea solea*. Aquaculture 4: 41-53.

The response of the developmental stages tested was examined under constant flow conditions using direct electrolysis of sea water as a source of chlorine. From LC_{50} determinations, the eggs of plaice were found to be more tolerant than the newly-hatched larvae, and for both plaice and Dover sole the tolerance of the larvae increased as their development proceeded up to metamorphosis. Less change in tolerance was evident with increasing size of fish after metamorphosis. Determinations of time to kill 50% of a test population showed that at chlorine concentrations only slightly higher than LC_{50} level the time for survival was considerably reduced. Growth of the metamorphosed fish of both species at sublethal levels only showed a very marked depression at concentrations very close to the LC_{50} level. There was some evidence of acclimation to chlorine during long exposure. The growth of fish in power station effluents should not be affected by the use of low level chlorination as an anti-fouling measure, since the chlorine is normally rapidly absorbed by reactions taking place in the sea water. Large fluctuations in the chlorine dose could however present a hazard.

Allonier, A.S. and M. Khalanski. 1998. Sea water chlorination by products. Journal. Research Oceanography 23(1): 21-24.

A wide range of methods have been developed to control biofouling in nuclear power plant cooling circuits using sea water; of these, low level chlorination is still the most commonly used. The oxidizing compounds generated by the chlorination of sea water are mainly hypobromous acid and bromamines when ammonia nitrogen is present. These compounds rapidly disappear from the water after its discharge in coastal waters. However, the organohalogenated (OX), mainly brominated compounds are more persistent. The volatile components of OX can easily be measured by gas chromatography (GC); bromoform is the predominant volatile product found in chlorinated sea water. Less volatile compounds, such as haloacetonitriles, halophenols and haloacetic acids, can also be measured by GC after liquid liquid extraction. Global measurement of OX extracted in an organic solvent (extractable organohalogenated compounds or EOX) by means of microcoulometry is also possible. The kinetics of bromoform formation and bromoform formation yields have been experimentally measured in sea water samples from nuclear power stations located on the English Channel coast in France: Gravelines, Penly and Paluel. Bromoform is rapidly generated in the chlorination range of 0.5 mg/L to 4.0 mg/L, with a molar yield of less than 1%. Field GC measurements carried out on chlorinated cooling waters at several power stations in France have confirmed. The experimental findings: dibromoacetonitrile and tribromophenol were found at lower concentrations than bromoform. However, the EOX method is not suitable for quantitative measurements of OX at low levels (<5 µg/L). The bromoform input in coastal waters due to chlorination at nuclear power stations is compared to estimations of the natural input of bromoform in sea water.

Allonier, A.S., M. Khalanski, V. Camel and A. Bermond. 1999. Characterization of chlorination by-products in cooling effluents of coastal nuclear power stations. Marine Pollution Bulletin 38(12): 1232-1241.

In power stations, the cooling effluents are chlorinated to avoid excessive biofouling. Yet, this disinfecting treatment leads to the formation of halogenated by-products. In spite of possible toxicity of such compounds towards aquatic organisms, there is an evident lack of information on the formation of halogenated compounds in chlorinated seawater samples. So, this study was undertaken to identify and quantify halogenated compounds (i.e., trihalomethanes, haloacetonitriles, halophenols and haloacetic acids) in effluents from three French nuclear power stations. In addition, experiments conducted in the laboratory allowed the determination of the kinetics of formation of the main compounds detected: bromoform, dihaloacetonitrile, 2,4,6-tribromophenol and dibromoacetic acid. Good agreement was obtained between the experiments conducted either on site or in the laboratory. In particular, evidence was given on the formation of brominated compounds (due to the high concentrations of bromide ions in seawater).

Amy, G., M. Siddiqui, K. Ozekin, H.W. Zhu and C.Wang. 1998. Empirically based model for predicting chlorination and ozonation by-products: trihalomethanes, haloacetic acids, chloral hydrate, and bromate. Washington, DC, Environmental Protection Agency Office of Water. 172 pp.

This report documents a series of statistically-based empirical models for use in predicting disinfection by-products (DBPs) formed during water treatment disinfection using chlorine or ozone. Each model was formulated through multiple step-wise regression analysis, and as such takes the form of a multiple regression equation. After formulation and calibration, model simulations were performed to compare predicted versus measured values, employing the same data base used in model calibration. Finally, each model was validated by using data derived from the literature. The relevant chlorination DBPs include haloaetic acids (HAAs), trihalomethanes (THMs), and chloral hydrate (CH). Bromate (BrO3-) served as the ozonation DBP of interest. For both chlorination and ozonation, dissolved organic carbon (DOC) has been used to represent the organic DBP precursor, while bromide ion (Br-) represents the inorganic precursor. For the chlorination DBPs, model variables includes water quality conditions; DOC, Br-, pH, and temperature; and treatment conditions represented by chlorine dose and reaction time. The models permit prediction of total HAAs (within the context of this report, total HAAs, THAA, corresponds to sum of six species, HAA6), total THMs, and CH as a function of time; supplementary models permit estimates of each of the four THM species, and each of six HAA species.

Anderson, C.D., D.J. Brown, B.A. Ketschke, E.M. Elliot and P.L. Pike. 1975. The effects of the addition of a fourth generating unit at the Salem Harbor generating station on the marine ecosystem at Salem Harbor. Report, Division of Marine Fisheries, Department of Fisheries, Commonwealth of Massachusetts, Boston, MA.

No abstract.

Anderson, D.R., R.M. Bean and C.I. Gibson. 1979. Biocide by-products in aquatic environments Annual report, October 1, 1977-September 30, 1978. NUREG/CR-0504; PNL-2806 DOE. Richland, WA (USA), Battelle Pacific Northwest Labs. 67 pp.

The Biocide By-Products in Aquatic Environments Program is composed of analytical chemistry and Biological phases with freshwater and marine Biological subdivisions. The objectives of the analytical studies are: to identify those chloroorganic chemical compounds that result from the addition of chlorine to fresh or saltwater; to develop methods for detecting chlorinated organics in the effluents discharged to receiving water bodies from nuclear stations; and to verify laboratory findings through analysis for chlorination by-products in water and biota samples from cooling water bodies of nuclear power stations. The objectives of the Biological studies are: to investigate the immediate toxicity of specific chlorination by-products (chloroform in freshwater and bromoform in marine waters); to evaluate the chronic toxicity of chlorination by-products; to follow their pathways of action; and to analyze for bioaccumulation or biomagnification of halogenated hydrocarbons on selected aquatic or marine biota.

Anderson, D.R., R.M. Bean, C.I. Gibson and T.O. Thatcher. 1978. Synthesis, pathways, effects, and fate of chlorination by-products in freshwater, estuarine and marine environments. Annual report, September 10, 1976-September 30, 1977. PNL-2909 DOE. DOE. Richland, WA (USA), Battelle Pacific Northwest Labs. 86 pp.

The study is composed of analytical chemistry and Biological divisions with freshwater and marine Biological subdivisions. The objective of the analytical phase is to identify those chemical compounds, other than the free and combined available halogen, which result from the addition of chlorine to fresh or saltwater. The objectives of the Biological studies are to investigate the immediate and relatively long-term toxicity of several chlorination by-products to selected aquatic biota; to follow their pathways of action; and to analyze for bioaccumulation or biomagnification. Initial analytical experimentation has been directed toward isolating and identifying nonpolar, lipophylic organohalogens that might be expected to be absorbed and biomagnified in the lipids of aquatic biota. Chlorinated natural fresh and marine water samples were obtained from Task IIa and b. Organic components were concentrated by forcing chlorinated and unchlorinated water through columns of XAD-2 resin using a positive displacement pump. Ether extracts of the XAD-2 columns were analyzed for haloforms by gas chromatography. Bromoform was found to be the major constituent in all chlorinated sea water samples. In contrast, chloroform was the only haloform produced from chlorinated freshwater. The Freshwater Biology 6-month chronic bioassay on rainbow trout has produced several results. The mortality rate, although low, indicated an interesting trend in response to increasing concentration of chlorination by-products. In addition to observed mortality, concentration was inversely related to other fish losses which are hypothesized to result from decreased aggressiveness. Fish length and weight at six months was also significantly reduced with increasing concentrations of chlorination by-products. A chronic bioassay of chlorination by-products was conducted with little-neck clams in the marine phase of the program.

Aprosi, G. 1988. Bryozoans in the cooling water circuits of a power plant. Proceedings of the International Association of Theoretical and Applied Limnology Conference.

The first aim of this study was to determine the conditions favoring the growth of colonies in the cooling water circuits. The following factors have been examined: growth rate, statoblast distribution, effects of temperature, light and water velocity. A quantity of approximately 120 x 10^6 phytoplankton cell/L provided a flourishing growth and the trophic parameter was not a limiting factor in the Loire River. The second aim was to design the methods most suitable for controlling bryozoan proliferation. It was concluded that shock chlorination, water deoxygenation and some anti-fouling paints couldn't be used or were proved inefficient.

Attrill, M., M. Power and R. Thomas. 1999. Modelling estuarine crustacea population fluctuations in response to physico-chemical trends. Marine Ecology Progress Series 178: 89-99.

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

Azanza, M., R. Azanza, A. Gedaria, H. Sententa and M. Idjao. 2001. Decimal reduction times of *Pyrodinium bahamense var. compressum* and *Escherichia coli* in chlorine- and ultraviolet-treated seawater. Letters in Applied Microbiology 33(5): 371-376.

Decimal reduction times (D-values) of the vegetative cells of *Pyrodinium bahamense var. compressum* and *Escherichia coli* in ultraviolet- and chlorine-treated seawater were established. Methods and Results: The cells of the test organisms were exposed to ultraviolet- and chlorine-treated seawater and maintained at 20-35 ppt salinity and 20 to 35°C. The dinoflagellate cells which cause Paralytic Shellfish Poisoning (PSP) were found to be more resilient than the bacterial cells. Ultraviolet treatment was found to be more effective than chlorine to both test organisms. Irreversible morphological changes in the treated dinoflagellate cells were noted, including protoplast discoloration, cellular membrane leakage and damage to the thecal armour. Conclusions: The vegetative cells of both test organisms in seawater were more sensitive to ultraviolet treatment than to chlorine exposure. Generally, the dinoflagellate cells were less susceptible than bacterial cells to both disinfection treatments. Significance and Impact of the Study: Results of this study may have significant implications in depuration procedures for mollusks and cleaning protocols for ballast waters of ships.

Baier, R., A. Meyer and R. Forsberg. 1994. Controlling the impact of zebra mussels on estuarine flow control/filtration structures by nontoxic, easy-release coatings. IAGLR. 166 pp.

Small, inland hydroelectric plants on Lake Ontario estuaries have been seriously impacted by accumulations of zebra mussels (*Dreissena polymorpha*) on their flow control/filtration structures--particularly trashracks--as well as the inplant turbines and housings. Using a series of test devices, ranging from small flow-controlled manifolds to full field-deployed coated trash racks, at Lake Glenwood (combining flows from Oak Orchard Creek, the Erie Barge Canal, and other sources), Medina, NY, it was demonstrated that maintenance of coating "critical surface tension" in the zone between 20 and 30 dynes/cm correlated with easy physical (hand wiping or water lance) removal of zebra mussels at the level of their byssus disc bases, leaving the structures clean and free of obstructions. On the other hand, materials with higher critical surface tensions required water lance pressures of more than 1, 500 psi to clean them, and this was achieved only by breaking the zebra mussel byssus threads to leave behind a "fuzzy, " debris-catching layer that was easily re-fouled. The most successful coatings are compliant, elastomeric silicones which have shown surprising toughness and abrasion resistance in both laboratory tests and field trials. Use of this nonpolluting control technology, based on understanding the interfacial biophysics of the zebra mussel attachment mechanism, can minimize the requirements for chlorination, thermal treatments, or poisonous paints in multi-use estuarine systems. Support from New York Sea Grant Institute, Niagara Mohawk Power Corporation, King Consulting, Inc., and Gilbert/Commonwealth, Inc. is gratefully acknowledged (DBO).

Bamber, R.N. and R.M.H. Seaby. 2004. The effects of power station enrichment passage on three species of marine planktonic crustacean, *Acartia tonsa* (Copepoda), *Cragnon cragnon* (Decapoda) and *Homarus gammarus* (Decapoda). Marine Environmental Research 57(4): 281-294.

Experiments have been undertaken exposing larval common shrimp (*Crangon crangon*) and lobster (*Homarus gammarus*) and adult copepods (*Acartia tonsa*) to the key stresses of entrainment within power-station cooling-water systems. The apparatus has enabled the testing of mechanical, thermal, chlorine and realistic pressure effects both alone and in combination, the range of stressors spanning the standard conditions found within a temperate coastal direct-cooled power station. Mechanical stresses affected only lobster larvae, pressure changes affected only the *Acartia* adults. Residual chlorine caused significant mortality of *Acartia* and shrimp larvae, but had no effect on lobster larvae even at 1 ppm. The temperature increment significantly affected all three species, with a synergistic effect on chlorine sensitivity in the shrimp larvae, but only temperatures higher than would be experienced in a normally operating power station affected the copepods. The majority of individuals of each species would survive passage through a power-station system under normal conditions. It is notable that, within the species tested, generalizations from the responses of one species to those of another are not valid.

Beauchamp, R.S.A. 1969. The use of chlorine in the cooling water system of a coastal power station. Chesapeake Science 10: 280.

In the intake conduits of coastal power stations marine fouling may build up to a remarkable extent. In two extreme cases the amount of marine fouling, consisting of barnacles, tube worms, mussels and debris, has exceeded 300 tons. The greatest hazard to station operation arises from the growth of mussels as these grow to a size that they can, when detached, block or partially block condenser tubes. The schedule now being used is to inject chlorine continuously at a rate of 0.5 ppm. It seems that combined chlorine or combined bromine, probably in the form of bromamines, is extremely distasteful to mussels. Bacterial slime that forms in the condensers can be controlled by injecting chlorine at 2-3 ppm for 15 minutes every 6 hours. The adoption of a schedule of low level chlorination for the control of marine fouling has made it possible to carry out trials on the farming of sea fishes using the warm water discharged from power stations.

Behrens, D.W. and B.C. Larsson. 1976. Effects of intermittent chlorination on selected invertebrate species indigenous to Diablo Cove- a laboratory study. Report No. 7846. 7-76.

No abstract.

Bellanca, M.A. and D.S. Bailey. 1977. Effects of chlorinated effluents on aquatic ecosystems in the lower James River. Journal Water Pollution Control Federation 49: 639-645.

The effects of chlorinated wastewater effluents on aquatic life were studied after massive fish mortalities occurred in the lower James River during the spring of 1973. Through the utilization of field bioassays, live box experiments, and laboratory toxicity tests, it was determined that chlorine and chloramines were acutely toxic to a wide variety of estuarine animals. Toxicity symptoms noted for fish included the occurrence of severely dislocated and broken vertebrae. Studies were also conducted on the relationship of fecal coliform levels in the receiving stream and chlorination at wastewater treatment plants. It was found that chlorine dosage rates at the wastewater treatment plants could be reduced significantly without an adverse effect on bacterial levels in the estuarine system.

Benanou, D., F. Acobas and P. Sztajnbok. 1998. Analysis of haloacetic acids in water by a novel technique: Simultaneous extraction-derivatization. Water Research 32(9): 2798-2806.

A simple and novel method has been developed for the analysis of haloacetic acids (HAAs), disinfection by-products (DBPs) formed during water chlorination. This method can be used to determine six of these acids, including chloro, bromo and chloro/bromo acids. The validity and reliability of the method were tested over 6 months on twenty French water samples. 50 ml of water are percolated over an ion-exchange resin, the strong acids are trapped and then eluted and simultaneously esterified to give their methyl derivatives by a methyl alcohol solution acidified with sulfuric acid. The esters are extracted by cyclohexane and analyzed by gas chromatography with electron-capture detection (GC/ECD). Dalapon is used as a tracer in order to monitor the extraction process and trichloropropane as the internal standard. The detection limits for the HAAs analyzed are between 0.1 µg/l and 0.2 µg/l. The analysis of different water samples showed that all the haloacetic acids, except monobromoacetic acid, were present. The total HAAs in water originating from surface waters was less than 50 µg/l, but could exceed 100 µg/l for water originating from reservoir waters. In underground waters, the concentration of HAAs was negligible.

Bender, M.E., M.H. Roberts, R. Diaz and R.J Huggett. 1977. Effects of residual chlorine on estuarine organisms. Pp. 101-108. In: L.D Jensen (ed). Biofouling Control Procedures Technology and Ecological Effects. Marcel Dekker, Inc., New York, NY.

No abstract.

Bidwell, J.R., D.S. Cherry, J.L. Farris, J.C. Petrille and L.A. Lyons. 1999. Effects of intermittent halogenation on settlement, survival and growth of the zebra mussel, *Dreissena polymorpha*. Hydrobiologia 394(1-3): 53-62.

The effect of intermittent (2-4 h/day) treatments with chlorine or bromine at levels of 0.5 and 1.0 mg/L (total residual oxidant) upon settling and growth of veliger larvae of the zebra mussel, *Dreissena polymorpha*, was examined in two successive flow-through studies. The work was conducted in a field laboratory which received a constant supply of water from western Lake Erie. Veliger densities in the water at the field site peaked at 530/L, while mussel densities on settling monitors reached 147,100/m^2 over the course of the two studies (early July to late September 1991). In Study 1, a 2-h daily treatment with 1.0 mg/L chlorine reduced mussel settling by 91% as compared with controls, although mussel densities of up to 6,000/m^2 still occurred. Treatment with 0.5 mg/L chlorine for 4 h/day produced a similar reduction in mussel settling during the second study. Bromine was less effective than chlorine at reducing settling of veligers. Mussels which remained settled in the treatment tanks had growth rates similar to controls, reaching 2-4 mm in length over a 30-day period. The intermittent halogen treatments similarly had no effect on whole body glycogen levels or growth of adult *D. polymorpha*. The intermittent chlorination regime used may therefore delay, but would not prevent a mussel fouling problem.

Blatchley, E.R. and Y. Xie. 1995. Disinfection and antimicrobial processes. Water Environment Research 67(4): 475-481.

Recent and pending amendments to water and wastewater disinfection policies are likely to bring about changes in disinfection processes. Many state regulatory agencies have incorporated stringent residual chlorine limitations on wastewater effluents. Ultraviolet radiation has been tested to replace some other means of disinfection in many waters and wastewaters. Ozone represents another alternative to halogen disinfection which has undergone extensive evaluation. Halogen-based applications remain the most frequently applied disinfection processes because of the relatively advanced state of knowledge regarding halogen systems and favorable economic considerations. Several other processes within water and wastewater treatment systems are effective in removal of pathogenic microorganisms. Most of these include some type of media filter to remove pathogens. Several techniques are available for the identification of pathogens in water. These methods help to determine the quality of the final water product after disinfection. Photolysis can break down free chlorine and affect the amount of residual chlorine. On-site generation of chlorine-based disinfectants by electrolysis of NaCl solutions is increasing. The formation of byproducts of disinfection, their toxicity and control has been extensively reviewed. Disinfection byproducts found in swimming pools included trihalomethanes, acetonitriles, chloral hydrate, and halogenated organic acids. Some disinfection byproducts were found to be mutagenic. Other treatment processes for the removal of bacterial cells include adsorption onto insoluble copolymer beads, ion exchange resins, ion inactivation, gamma irradiation, and electrochemical inactivation. The attachment of bacteria to surfaces during disinfection and biofilm formation may affect the disinfection process.

Block, R.M. 1977. Physiological responses of estuarine organisms to chlorine. Chesapeake Science 18: 158-160.

Chlorine produced stress to estuarine organisms may be indicated by physiological responses that are not reflected in mortality studies. The physiological parameters selected should relate to the functional physiology for a particular species. Time of exposure should be correlated with the behavior patterns for the test species. More research is required using multivariate design on the effects of chlorine on selected euryhaline species at various salinities.

Block, R.M., J.C. Rhoderick and S.R. Gullans. 1977. Physiological responses of white perch (*Morone americana*) to chlorine. Association Southeastern Biologists Bulletin 24: 37.

No abstract.

Block, R.M., D.T. Burton, S.R. Gullans and L.B. Richardson. 1978. Respiratory and osmoregulatory responses of white perch (*Morone americana*) exposed to chlorine and ozone in estuarine waters. Pp. 351-360. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Bolster, C.H., J.M. Bromley and S.H. Jones. 2005. Recovery of chlorine-exposed *Escherichia coli* in estuarine microcosms. Environmental Science & Technology 39(9): 3083-3089.

Laboratory microcosm experiments were performed to determine whether chlorine-exposed *Escherichia coli* are capable of recovery (i.e., increase in numbers of culturable cells) in estuarine waters and if so what water-quality parameters are responsible for this recovery. Suspensions of *E. coli* were exposed to 0.5 mg/L of chlorine for 5 minutes followed by dechlorination with sodium thiosulfate. The chlorine-exposed bacteria were introduced into 2-L microcosms containing estuarine water collected from the seacoast region of New Hampshire. Culturable cells in the microcosms were enumerated at 0, 10, 24, 48, and 74 h. In all estuarine microcosms the number of culturable cells increased by factors ranging from 2.8 to 50 over the 74-h incubation period. Multiple linear regression analyses indicated that ammonium and salinity were most significantly correlated with the recovery of *E. coli* over the 74-h incubation period; however, ammonium concentrations were strongly correlated with dissolved organic carbon and total dissolved nitrogen, making it impossible to determine with any degree of certainty the unique effect nitrogen or carbon had on recovery. The extensive recovery observed in our study indicates that following exposure to concentrations of chlorine that cause cell injury rather than death, numbers of culturable *E. coli* may increase significantly when discharged into estuarine waters. Thus, depending on the effectiveness of the chlorination process, the regular monitoring of chlorinated wastewater treatment effluent may underestimate the true impact on water-quality and public health risks.

Bongers, L.H., B. Bradley, D.T. Burton, A.F. Holland and L.H. Liden. 1977. Biotoxicity of bromine chloride and chlorine treated power plant condenser cooling water effluent. Report by Martin Marietta Corporation.

The dechlorination of chlorinated sewage effluent was studied to demonstrate that such a process would effectively eliminate toxicity attributable to the chlorine produced oxidants (CPO). The design of the study stipulated that the simulated effluent chlorine concentration should be the same as that in an actual plant effluent, 2 mg/L, as occurs at the James River Sewage Treatment Plant. A portion of the chlorinated sewage effluent was dechlorinated with sodium thiosulfate, and the dechlorinated waste was diluted with estuarine water in the same proportions as the chlorinated waste. *Menidia menidia*, *Palaemonetes pugio*, and *Crassostrea virginica* were exposed to both the chlorinated and dechlorinated wastewater. Mortalities were noted in *M. menidia* and *P. pugio* due to high concentrations of chlorinated effluent, whereas similar concentrations of dechlorinated wastes did not cause mortalities. Mortalities in the chlorinated waste were correlated with chlorine residuals. The chlorinated wastes depressed the shell deposition rate of *C. virginica* below 50% of controls at all doses. Dechlorinated waste allowed shell deposition greater than 50% of controls. The occurrence of some growth inhibition, however, was noted in *C. virginica* exposed to dechlorinated waste, which suggests the presence of toxic material other than chlorine in the waste.

Bradley, B.P. 1978. Comparison of residual biotoxicity of chlorine and bromine chloride to copepods. Technical Report No. 47, University of Maryland, Water Resources Research Center, College Park, MD.

No abstract.

Brook, A.J. and A.L. Baker. 1972. Chlorination at power plants: impact on phytoplankton productivity. Science 176 (4042): 1414-1415.

Studies of the effects of passage through a power plant on river phytoplankton have shown that chlorination depresses rates of photosynthesis and respiration to a much greater extent than does heating.

Brooks, A.S. 1974. Phytoplankton entrainment studies at the Indian River estuary, Delaware. Pp. 105-111. In: L.D Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD.

No abstract.

Browdy, C.L., T. Smyth and D. Bratvold. 1998. Preliminary development of a biosecure shrimp production system. Aquaculture '98 Book of Abstracts. P. 71.

The US Marine Shrimp Farming Program has developed fast growing, high health and genetically improved shrimp stocks, disease diagnosis and control protocols, and environmentally friendly growout technologies to provide a basis for the profitable

controlled production of healthy shrimp. Nevertheless, outbreaks of viral disease continue to cause crop failures in Texas and South Carolina. The present study explores strategies for more biosecure growout technologies. The tested system reduced the likelihood of pathogen contamination by disinfection of intake water and physical exclusion of some possible vectors which could carry disease. A greenhouse structure erected over a 0.1 ha pond was covered with a plastic roof and walls of fine mesh shade cloth to allow air exchange. The sediment was dried and limed. A 5.5% bleach solution was poured over a small section of the sediment near the drain that did not dry completely. Incoming seawater was disinfected with chlorine at a CT of 1200 to 2000 min x ppm by pumping sand filtered seawater and a concentrated chlorine solution into a raceway contact chamber and then into the pond over a nine-day period. Disinfection success was assessed by colony forming units (CFU) on nutrient media and direct bacterial counts by fluorescence microscopy. At least 99% of the bacteria and yeast present in the filtered seawater were destroyed by this disinfection procedure. However, CFU were abundant on all plates from the sediment site, indicating a lack of sediment disinfection, despite significant residual chlorine in the overlying water column, and likely contamination of the interstitial water with water column water during the sampling process. These results suggest the difficulty in achieving sediment disinfection, however, destruction of pathogens may not require complete disinfection. The microbial community was monitored throughout the season. The following parameters were measured weekly: bacterial abundance, phytoplankton and zooplankton abundance and biomass, oxygen consumption and nitrification rates, and total ammonia concentration. Chlorinated water additions ceased on Day 9, and residual chlorine concentrations dropped rapidly. This was followed by a sharp increase in water column bacterial abundance. Two days after residual chlorine reached undetectable levels, the pond was fertilized and inoculated with a pure culture of *Chaetoceros gracilis* (Day 13). The initial modest *C. gracilis* bloom (Day 16) was followed by a large bacterial bloom and then a large mixed algal bloom (Day 30), of which *C. gracilis* was a small component. The initial very large fluctuations in phytoplankton and appeared to reach more normal fluctuation levels by Day 50. The initial bloom and stabilization of nitrifying bacteria lagged about 20 days behind the other measured groups, making nitrifiers the last group to stabilize. The biosecure pond was stocked at a density of $100/M^2$ on Day 16. Survival was 70%, mean size at harvest was 13g, for a production rate of 9109 kg/ha/crop. Feeding trays were used to monitor consumption but feed was offered at a constant rate from stocking to harvest. Overall the food conversion ratio was 2.2:1. The study provided hands on experience in designing and managing a biosecure production strategy providing useful basic information for future development efforts.

Brungs, W.A. 1973. Effects of residual chlorine on aquatic life. Journal of Water Pollution Control Federation 45(10): 2180-2193.

Increased use of Cl and recent studies of residual Cl toxicity in aquatic systems have emphasized the need for close scrutiny of present disinfection procedure. This review discusses Cl uses and Cl chemistry and emphasizes toxicity studies in the field and in the lab. Interim criteria, based on knowledge to date, for permissible concs of total residual Cl are: (a) in areas receiving wastes treated continuously with Cl, not to exceed

0.01 mg/L for the protection of more resistant organisms only, or not to exceed 0.002 mg/L for the protection of most aquatic organisms; and (b) in areas receiving intermittently chlorinated wastes, not to exceed 0.2 mg/L for a period of 2 hr /day for more resistant spp of fish, or not to exceed 0.04 mg/L for a period of 2 hr/day for trout and salmon. If free Cl persists, more restrictive criteria are warranted. Alternate procedures or substitutes for chlorination should be investigated.

Buckley, J.A. 1976. Acute toxicity of residual chlorine in wastewater to coho salmon (*Oncorhynchus kisutch*) and some resultant hematological changes. Journal of Fisheries Research Board Canada. 33: 2854-2856.

Juvenile coho salmon were exposed to treated wastewater containing lethal levels of total residual chlorine (TRCl2) with seawater diluents under continuous flow conditions. The 96-h TL50 [tolerance limit to 50% of test fish] was 0.07 mg/L TRCl2 (4% effluent). Exposure resulted in a slight reduction (significant P = .05) in Hb, a slight increase (significant P = .05) in methemoglobin, and a temporary decrease (not significant P = .05) in percentage of circulating immature erythrocytes.

Buckley, J.A. 1977. Heinz body hemolytic anemia in coho salmon (*Oncorhynchus kisutch*) exposed to chlorinated seawater. Journal Fisheries Research Board Canada. 34: 215-224.

Fingerling coho salmon (*O. kisutch*) were exposed for 12 wk to various concentrations of treated wastewater contaning total residual chlorine (TRCl2) with riverwater diluent under continuous flow conditions. Levels of TRCl2 averaging 0.003-0.05 mg/L resulted in mild to pronounced symptoms of hemolytic anemia, including an increase in numbers of circulating immature erythrocytes, pathological changes in erythrocytes, and a reduction in packed cell volume and Hb levels. In addition, Heinz bodies were formed at the 0.012 and 0.05 mg/L TRCl2 levels. The hematologic changes were attributed to the oxidative nature of TRCl2.

Buckley, J.A. and R.I. Matsuda. 1972. Toxicity of the West Point treatment plant effluent to coho salmon, *Oncorhynchus kisutch*. Report, Municipality of Metropolitan Seattle, WA.

No abstract.

Buckley, J.A. and R.I. Matsuda. 1973. Toxicity of the Renton treatment plant effluent to coho salmon, *Oncorhynchus kisutch*. Report, Municipality of Metropolitan Seattle, WA.

No abstract.

Buckley, J.A., C.M. Whitmore and R.I. Matsuda. 1976. Changes in blood chemistry and blood cell morphology in coho salmon (*Oncorhynchus kisutch*) following exposure to sublethal levels of total residual chlorine in municipal wastewater. Journal Fisheries. Research Board Canada 33: 776-782.

Yearling coho salmon (*O. kisutch*) were exposed for 12 wk to either 0.3, 1.1 or 3.6% chlorinated municipal sewage treatment plant effluent with seawater diluent (average salinity 28%) under continuous flow conditions. The maximum safe concentration of effluent lies between 0.3-1.1% (average total residual chlorine [TRCl2] content 0.003 and 0.009 mg/L, respectively). Effluent concentration of 0.3% produced no discernible effects on the fish. Concentrations of 1.1 and 3.6% (average content of TRCl2 0.030 mg/L) resulted in reductions of Hb and hematocrit to levels indicative of anemia. Observations of the erythrocytes revealed lysed and degenerating cells, increased numbers of circulating immature cells and abnormal cells. These hematological effects are attributed to the oxidative nature of TRCl2.

Burton, D.T. and S.L. Margrey. 1979. Control of fouling organisms in estuarine cooling water systems by chlorine and bromine chloride. Environmental Science Technology 13(6): 684-689.

The relative antifouling effectiveness of chlorine and bromine chloride under intermittent and continuous modes of application in low velocity flow areas was evaluated at an estuarine power plant located on the Chesapeake Bay. No significant difference in the control of fouling organisms was found on the average between similar concentrations of chlorine and bromine chloride. Significant differences in fouling were found between intermittent and continuous halogenation on both clean and prefouled surfaces. Continuous halogenation was more effective over an entire fouling season in controlling primary, secondary, and adventitious fouling communities than intermittent halogenation for periods up to 2 h/day. Continuous halogenation at 0.3 mg/L total residual halogen was more effective than 0.1 mg/L total residual halogen during late spring and summer; no difference was found between the 2 concentrations during the early fall.

Burton, D.T. and D.J. Fisher. 2001. Chlorine dioxide: the state of science, regulatory, environmental issues, and case histories. Wye Research and Education Center Report: 16 pp.

The use of chlorine by electric utilities and other surface water users to inhibit biofouling and the chlorination of wastewater by POTWs to eliminate the discharge of pathogenic organisms are widespread practices. A number of surface water users in the Great Lakes region recently expressed an interest in using chlorine to control the zebra mussel (*Dreissena polymorpha*) which was introduced from Europe in the mid-1980s. It is well known, however, that chlorine-produced oxidants may be toxic to aquatic life when discharged into receiving waters. In addition, chlorine reacts with ammonia and chlorinated hydrocarbons to form various chloramines and trihalomethanes, which have long half-lives and similar toxicities relative to free chlorine.

Burton, D.T., L.W.J. Hall and S.L. Margrey. 1979a. Interactions of chlorine, temperature change and exposure time on survival of striped bass (*Morone saxatilis*) eggs and prolarvae. Journal Fisheries Research Board Canada 36: 1108-1113.

Effects of total residual chlorine (TRC), change in temperature (ΔT) and exposure time were established for eggs and prolarvae of striped bass, *M. saxatilis*, under test conditions designed to simulate entrainment by power plants. Prolarvae were more sensitive than eggs under the same test conditions. In contrast to the predominant effect of TRC and exposure time on eggs, TRC, ΔT and exposure time were all important in causing mortality of prolarvae. [A predictive mortality model was discussed.] In an evaluation of the potential effects of chlorinated power plant cooling waters to striped bass ichthyoplankton, a systematic study must be made of the interactions of TRC, ΔT and exposure time.

Burton, D.T., L.W. Hall and S.L. Margrey. 1979b. Multifactorial chlorine, ΔT and exposure duration studies of power plant effluents on esturarine ichthyoplankton. Mid-Atlantic Industrial Wastes Conference. Pp. 223-229.

No abstract.

Cakiroglu, C. and C. Yurteri. 1998. Methodology for predicting cooling water effects on fish. Journal of Environmental Engineering 124(7): 612-618.

The mathematical model presented here predicts the long-term effects of once-through cooling water systems on local fish populations. The fish life cycle model simulates different life stages of fish by using appropriate expressions representing growth. All of abstract.

Capuzzo, J.M. 1977. The effects of free chlorine and chloramines on growth and respiration rates of larval lobsters (*Homarus americanus)*. Water Research 11: 1011-1024.

The length, dry weight and standard respiration rate of larval lobsters (*H. americanus*) were monitored for 19 days following a 60 minute exposure at 25°C to 1.0 mg/L applied free Cl and 1.0 mg/L applied chloramine. Compared to control organisms, significantly lower increases in dry weight ($P < 0.05$) and significant reductions in standard respiration rates ($P < 0.01$) were measured among exposed organisms; greater differences were detected among chloramine exposed organisms. Acute exposure to free Cl or chloramine results in subsequent reductions in growth and metabolic activity of larval lobsters.

Capuzzo, J.M. 1980. Impact of power-plant discharges on marine zooplankton: A review of thermal, mechanical and biocidal effects. Helgolander Meeresuntersuchungen. European Marine Biology Symposium, Helgoland (FRG), 23 Sep 1979.

The relative importance of thermal, mechanical and biocidal stresses to marine zooplankton entrained in cooling waters from coastal power-plant operations is dependent on specific features of power-plant design and siting. Toxic effects of power-plant operations will vary with (1) the degree of mechanical stress induced by pumping velocities of cooling water; (2) the physical and chemical interaction of receiving and discharge waters; (3) the dosage of chlorine or other biocide added to cooling waters for fouling control: (4) the exposure time to stress condition experienced during passage through condenser conduits and discharge canals and (5) the nature of receiving waters, affecting the production and availability of the various halogen toxicants formed upon chlorination of seawater. Because of these variables, the problem of entrainment-induced mortality of zooplankton and the resulting effects on secondary production in receiving waters is difficult to assess.

Capuzzo, J.M., S.A. Lawrence, J.A. Davidson and M. Libni. 1976a. The differential effects of free and combined chlorine on juvenile marine fish. Estuarine Coastal Marine Science 5: 733-741.

The differential effects of free chlorine and chloramine on 3 spp. of juvenile marine fish were investigated in continuous flow bioassay units. The toxicity of both chlorine forms to winter flounder, *Pseudopleuronectes americanus*, scup, *Stenotomus versicolor* and killifish, *Fundulus heteroclitus*, appeared to be a threshold effect: an abrupt increase in mortality was observed over a narrow range of toxicant concentrations. The 3 spp. were similar in their responses to free chlorine, the more toxic of the 2 chlorine forms. There was a difference in chloramine toxicity among the 3 spp.; killifish were more susceptible than either of the other 2 spp., probably reflecting differences in metabolic regulation or uptake rates. Behavioral aberrations, distended gills and erratic swimming behavior, of winter flounder and scup and significant reductions in standard respiration rates of killifish were observed with exposure to chlorine or chloramine concentrations approaching lethal levels.

Capuzzo, J.M., S.A. Lawrence and J.A. Davidson. 1976b. Combined toxicity of free chlorine, chloramines and temperature to stage I larvae of the American lobster *Homarus americanus.* Water Research 10: 1093-1099.

The differential effects of free Cl and chloramine on stage I larvae of *H. americanus* were investigated in continuous flow bioassay units. Applied chloramine was more toxic than corresponding concentrations of applied free Cl to lobster larvae with estimated LC_{50} values at 25°C of 16.30 mg/L applied free Cl and 2.02 mg/L applied chloramine. The synergistic effect of temperature on the toxicity of both free Cl and chloramine was also demonstrated. Exposure to applied free Cl at 20°C resulted in no significant mortality of test organisms, whereas exposure at 30° resulted in an estimated LC_{50} value of 250 mg/L. Applied chloramine was considerably more toxic with an estimated LC_{50} value at 20° of 4.08 mg/L and at 30° of 0.56 mg/L. The action of each toxicant appeared to be an alteration of standard metabolic activity as revealed by changes in respiration rates during and after exposure to applied free Cl and chloramine. Initial respiratory stress was detected during exposure to 0.05 mg/L applied chloramine

and 5.00 mg/L applied free Cl. Reductions in respiration rates 48 h after exposure were observed with exposure to all concentrations tested, similar results being obtained following exposure to 0.05 mg/L applied chloramine and 0.10 mg/L applied free Cl. These results are indicative of the need for information in addition to that obtained in standard bioassays for an adequate assessment of Cl toxicity. The apparent Cl demand of the seawater used in this study was determined after removal of particulate and dissolved organics and ammonia. Approximately 18% of the applied level of free Cl and chloramine was recovered as residuals, measured by amperometric titration; no reason for this low recovery was determined. Until it has been established that undetected Cl and chloramine in seawater do not result in the production of toxic compounds, both applied and residual levels should be reported in toxicity studies.

Capuzzo, J.M., J.C. Goldman, S.A. Lawrence and J.A. Davidson. 1977. Chlorinated cooling water in the marine environment: development of effluent guidelines. Marine Pollution Bulletin 8: 161-162.

The effects of free chlorine and chloramine on stage I lobster larvae and juvenile killifish were investigated in continuous flow bioassay units. In comparing mortality and changes in standard respiration rates during and after exposure to either chlorine form, significant respiratory stress was observed with exposure to sublethal levels. Sublethal responses to free and combined chlorine should be considered when establishing regulations for chlorine residuals in cooling waters.

Carpenter, E., B.B. Peck and S.J. Anderson. 1972. Cooling water and productivity of entrained phytoplankton. Marine Biology (Berlin) 16(1): 37-40.

No abstract.

Carpenter, E., B.B. Peck and S.J. Anderson. 1974a. Copepod and chlorophyll: A concentrations in receiving waters of a nuclear power station and problems associated with their measurements. Estuarine Coastal Marine Science 2:83-88.

No abstract.

Carpenter, E., B.B. Peck and S.J. Anderson. 1974b. Summary of entrainment research at the Millstone Point Nuclear Power Station, 1970 to 1972. Pp. 31-35. In: L.D. Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD.

No abstract.

Carpenter, E., B.B. Peck and S.J. Anderson. 1974c. Survival of copepods passing through a nuclear power station on Long Island Sound, USA. Marine Biology 24: 49-55.

About 70% of the copepods entering the cooling water system of a nuclear power plant on northeastern Long Island Sound (USA) are not returned to the Sound in the effluent. Copepod mortalities are caused by the mechanical or hydraulic stresses of passage, although our experimental design could not determine whether heat or chlorination could cause mortality in the absence of mortality induced by hydraulic stress. After passing through the power plant, copepods sink rapidly (~2.5 times faster than controls). This leads to an increase in concentrations of copepods suspended in the deep water (25 to 30 m) of the effluent pond. About half of the live copepods collected at the discharge and held *in situ* died within 3.5 days, and 70% died within 5 days, whereas only 10% of those from the intake died in 5 days. About 60% of the copepods observed suspended in deep water in the pond were dead. The copepod mortality caused by the power plant reflects the loss in secondary production occurring below about 270×10^3 m^2 of sea surface in Long Island Sound annually. This loss represents a reduction of about 0.1% in the annual secondary production over a 333 km^2 area of Long Island Sound adjacent to the power plant. Highest losses occurred during the spring (April, 1.4×10^6 g dry weight), the lowest in autumn (November, 45.8×10^3 g). If the same copepod loss rate exists for all power plants in Long Island Sound, then secondary production in 1.69×10^6 m^2, or 0.05% of the total copepod production may be lost annually. A comparison of the surface outflow from Long Island to Block Island Sound with the water entrained through Millstone Unit One, and the 70% copepod loss rate in the latter area, indicates that Unit One eliminates about 0.1 to 0.3% of the copepod production in eastern Long Island Sound. This calculation compares favorably with losses computed from production data.

Carpenter, J.H., C.A. Smith and R.G. Zika. 1981. Reaction products from the chlorination of seawater. Final report 15 Jul 75-14 Jul 80 PB-81-172280. Miami, FL (USA), Miami Univ., FL Rosenstiel School of Marine and Atmospheric Sciences, 62 pp.

Chemical treatment of natural waters, in particular the use of chlorine as a biocide, modifies the chemistry of these waters in ways that are not fully understood. The research described in this report examined both inorganic and organic reaction products from the chlorination of seawater using a variety of analytical approaches. Some analytical methods in widespread current use underestimate the residual oxidants in chlorinated seawater by as much as 70% depending upon the detail of the procedure. The chlorination of seawater in the presence of light produces substantial quantities of bromate ions which can influence standard analytical procedures and represents an unknown factor in estuarine and coastal waters. The copper complexing capacity of Biscayne Bay, Florida water was found to be substantially reduced with the addition of chlorine. Analysis was made by anodic stripping voltammetry on water samples after successive additions of copper sulfate solution. Laboratory chlorination of water from the intake of the Port Everglades, Florida power plant produces bromoform levels comparable to that found in the plant discharge. These results are in contrast to results reported in the literature for a power plant on the Patuxent estuary in Maryland, so that bromoform production appears to be site-specific. Chloroform extracts of chlorinated Biscayne Bay water are found to contain halogenated compounds which are new and different, and which pose unusual analytical problems. Studies using GC/ECD, GC/MS,

HPLC, H NMR, differential pulsed polarography and other techniques on natural extracts and synthesized compounds are reported.

Chang, W.Y.B. and R. Rossmann. 1984. Effects power plant entrainment on phytoplankton response, International Association of Theoretical and Applied Limnology/Travaux Conference. Congress of the International Association of Limnology- Lyon, France. 21 Aug 1983.

Effects of power plant entrainment on phytoplankton response consist primarily of four types: thermal and hydromechanical impacts, and the impacts of biofouling control and of erosion and corrosion of power plant components. A study focusing on these issues was conducted between February 1980 and May 1982 at the D.C. Cook Plant on the southeastern shore of Lake Michigan. The results show that changes in chlorophyll and phaeophytin concentration are not significant in water which has passed through the condenser cooling system, but the reduction in primary productivity as measured by C^{14} was remarkable, ranging from 20% similar to 80%. While the former show no significant damage done by increased temperature and hydromechanical abrasion on phytoplankton, the latter indicates a significant inhibition of the photosynthesis of these phytoplankton.

Chapman, G.A., D.L. Denton and J.M. Lazorchak. 1995. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to west coast marine and estuarine organisms U.S. EPA, National Exposure Research Laboratory, Office of Research and Development. 661 pp.

No abstract.

Choi, D.H., J.S. Park, C.Y. Hwang, S.H. Huh and B.C. Cho. 2002. Effects of thermal effluents from a power station on bacteria and heterotrophic nanoflagellates in coastal waters. Marine Ecology Progress Series 229: 1-10.

To investigate effects of thermal effluents from a coastal power station on bacteria and heterotrophic nanoflagellates (HNF) in adjacent coastal waters, surface distributions of bacteria and HNF and interrelations between microbial and environmental variables were studied in November 1998 and July, August and November 1999 near Hadong Power Station, Korea. In addition, manipulation experiments with treatments of high temperature (40°C; temperature in the cooling system of the power station) and additions of hypochlorite and dilution experiments of thermal effluents with intake seawaters were carried out. Water temperature in the discharge-channel was always 5 to 10°C higher than the ambient temperature, but bacterial production, HNF abundance and grazing rates on bacteria, as well as chlorophyll a concentrations, were always lower there and increased with distance from the power station. Manipulation experiments showed that addition of hypochlorite had much more deleterious effects on bacteria and HNF (95 to 98% inhibition of bacterial production and 25 to 45% decrease in HNF abundance at 0.13 ppm of residual chlorine) than high temperature (9 to 39% inhibition of bacterial production but no inhibition of HNF abundance at 40°C). Dilutions of thermal effluents

from the outlet and condenser tube with intake seawater would bring < 0.03 ppm of residual chlorine, but inhibitory effects of thermal effluents on bacterial production and HNF grazing activity (23 to 69% inhibition of bacterial production and 31 to 36% inhibition of HNF grazing) were shown, indicating inhibitory potential of chlorination by-products in the discharged water on coastal microbes. Analyses of horizontal distributions of microbial variables, manipulation and dilution experiments gave consistently similar results of inhibitory effects of thermal effluents on bacteria and HNF. Our work suggests that a microbial ecological approach is useful in estimating influences of thermal Pollution on microbes in aquatic environments.

Cooke, S.J. and J.F. Schreer. 2001. Additive effects of chlorinated biocides and water temperature on fish in thermal effluents with emphasis on the Great Lakes [of North America]. Reviews in Fisheries Science 9(2): 69-113.

We reviewed the literature on the effects of chlorine on selected Great Lakes fishes during the summer when chlorine is used to control biofouling in cooling systems at power generating stations. Mortalities of fish are usually not solely due to chlorine toxicity but to complex additive functions and interactions of various stressors, in particular temperature. Elevated temperature appears to be important in magnifying the effects of the toxicity of chlorine to fish. When chlorination is used at temperatures near the thermal maxima, but not sufficiently high to exclude fish, high mortality rates can be expected. Most of the fish that lose equilibrium during exposure do not survive. Fish exposed to sublethal levels of chlorine become lethargic and often gulp air and frequently suffer increased predation pressures from birds and other fish. Additionally, hematological and biochemical disturbances, and potentially irreversible gill damage, may impair the lifetime fitness of fish exposed to chlorine. The sensitivity of different species of fish to chlorine toxicity varies widely. As such, chlorination regimes should be evaluated on a daily basis to account for differences in species composition and water temperature Most of the chlorine exposure concentrations reported in the literature are for 50% mortality, but the highest concentration resulting in no mortality, loss of equilibrium, or sublethal effects, is a more appropriate value for management and conservation. We also advocate comprehensive ecological risk assessments to determine the scope of impact on all organisms, not just fish. Only a series of in situ and laboratory studies for each situation will provide biologically meaningful values and the basis for relevant regulations.

Cripe, C.R. 1979. An automated device (AGARS) for studying avoidance of Pollutant gradients by aquatic organisms. Journal Fisheries Research Board Canada 36: 11-16.

No abstract.

Davies, R.M. and L.D. Jensen. 1975. Zooplankton entrainment at three mid-Atlantic power plants. Journal Water Pollution Control Federation 47: 2130-2142.

No abstract.

Davis, M.H. and J. Coughlin. 1978. Response of entrained plankton to low-level chlorination at a coastal power station. Pp. 369-376. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Dempsey, C.H. 1986. The exposure of herring postlarvae to chlorine in coastal power stations. Marine Environmental Research 20 (4): 279-290.

Postlarvae of *Clupea harengus* were exposed to chlorinated sea water for 30 minutes, to simulate passage through a typical power station cooling water circuit, and 24-h, during which detectable chlorine decayed away, to simulate a 'worst case' exposure. Twenty-four hour LC_{50s} were 0.63ppm initial concentration for 30 minutes exposure and 0.36ppm initial concentration for 24-h exposure.

Domart-Coulon, I., S. Auzoux-Bordenave, D. Doumenc and M. Khalanski. 2000. Cytotoxicity assessment of antibiofouling compounds and by-products in marine bivalve cell culture Toxicology In Vitro 14(3): 245-251.

Short-term primary cell cultures were derived from adult marine bivalve tissues: the heart of oyster *Crassostrea gigas* and the gill of clam *Ruditapes decussatus*. These cultures were used as experimental in vitro models to assess the acute cytotoxicity of an organic molluide, Mexel-432 registered, used in antibiofouling treatments in industrial cooling water systems. A microplate cell viability assay, based on the enzymatic reduction of tetrazolium dye (MTT) in living bivalve cells, was adapted to test the cytotoxicity of this compound: in both in vitro models, toxicity thresholds of Mexel-432 were compared to those determined in vivo with classic acute toxicity tests. The clam gill cell model was also used to assess the cytotoxicity of by-products of chlorination, a major strategy of biofouling control in the marine environment. The applications and limits of these new in vitro models for monitoring aquatic Pollutants were discussed, in reference with the standardized Microtox registered test.

Dressel, D.M. 1971. The effects of thermal shock and chlorine one the estuarine copepod, *Acartia tonsa*. MS thesis, University of Virginia, Charlottesville, VA.

No abstract.

Enstrom, D.G and J.B. Kirkwood. 1974. Median tolerance limits of selected marine fish and lobster larvae to temperature and chlorinity. Appendices IIB3 in Supplement to Preoperational Report on Pilgrim Nuclear Studies. Boston Edison Co., Boston, MA.

No abstract.

Eppley, R.W., E.H Renger and P.M. Williams. 1976. Chlorine reactions with seawater constituents and the inhibition of photosynthesis on natural marine phytoplankton. Estuarine Coastal Marine Science 4: 147-161.

The time course of chlorine disappearance was followed in filtered (1), non-filtered (2), and u.v.-oxidized (3) seawater. In (1) and (2) there was an initial rapid decline in both free and residual chlorine followed by a slower decline of these species. No decline was observed in (3), suggesting that the removal of organic matter and/or the oxidation of metal ions by u.v.-oxidation removed those molecular species that reacted with chlorine. Reaction rate was more rapid in (2) than in (1), suggesting that particulate organic matter may also react with chlorine. Reaction kinetics of chlorine were complex but approximated second order in the slow phase. The inhibition of phytoplankton photosynthesis by chlorine was studied by adding hypochlorite to samples. Chlorine concentrations required for 50 % inhibition varied with exposure time. For 24-h incubations such inhibitions took place with residual chlorine concentrations of 10^9. The inhibition appeared to be irreversible. The deleterious impact on marine phytoplankton by the use of seawater for cooling power plants lay in the use of chlorine to prevent slime build-up on the condenser system parts.

Erickson, S.J. and A.J. Freeman. 1978. Toxicity screening of fifteen chlorinated and brominated compounds using four species of marine phytoplankton. Pp. 307-310. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Erickson, S.J. and H.R. Foulk. 1980. Effects of continuous chlorination on entrained estuarine plankton. Journal Water Pollution Control Federation 52(1): 44-47.

The effects of continuous chlorination in running sea water on entrained plankton were examined. The concentration of ATP was used as an indicator of biomass because: it is present in all living cells; the concentration is proportional to the living biomass; and dead cells lose ATP rapidly. Effects were measured by biominescence; luciferin-luciferase reagents from firefly lanterns were used to analyze ATP concentration. Results indicate that ATP measurement is an accurate, effective means of evaluating damage done to planktonic organisms by continuous chlorination. Further studies of the effects of low-concentration, continuous chlorination are recommended.

Fayad, N.M. and S. Iqbal. 1987. Chlorination byproducts of Arabian Gulf seawater. Bulletin of Environmental Contamination and Toxicology 38(3): 475-482.

Some researchers have related the toxicity of chlorinated seawater to the residual chlorine contents of the water. This has resulted in the establishment of guidelines for reducing the chlorine levels in the discharged water. However, when chlorine is added to seawater, a great proportion of it is consumed in the oxidation of the naturally occurring organic and inorganic materials of the water. Therefore, the harmful effects of the chlorinated discharges can most probably be attributed to the reaction by-products. Very little information is available about these by-products.

Ferro-Soto, B. 2001. Effect of chlorine on different bacterial groups and effectiveness of the purification of sewage in harvested areas. Journal of Shellfish Research 20(3): 1311-1314.

Besides microbiological monitoring programs, it is important in shellfish harvesting areas to understand the process of purification of sewage discharged in harvesting areas. The objective of this study was to evaluate the importance of purification, the effectiveness of chlorination, and the influence in these areas. Chlorine produced significant reductions on all studied bacterial groups and reductions were among one and two orders of magnitude, being lower for fecal streptococci and aerobic bacteria at 25°C. High quantitative variability was observed with regard to the number of bacteria presents in these waters (W1, W2, W3) but qualitative variability is unknown. Correlation among shellfish samples and W3 (effluent discharged in harvesting areas) was not observed.

Flemer, D.A. 1974. The effects of entrainment on phytoplankton at the Morgantown Steam Electric Station Potomac River Estuary, September 5-8, 1972. Pp. 163-164. In: L.D Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD.

No abstract.

Flemer, D. and J.A. Sherk. 1977. The effects of steam electric station operation on entrained phytoplankton. Hydrobiologia 55:33-44.

The effect of entrainment on estuarine phytoplankton was studied at 3 steam electric stations located on tributaries of Chesapeake Bay [USA]. In most cases, Cl rather than heat was implicated as the most important factor in the reduction of the rate of C assimilation. The reduction of C assimilation in the mixture of plant effluent and augmentation water was greater than explained as mechanical and heat effects. Cl was judged as the primary factor under these conditions. One study that involved 3 consecutive days exemplified the problem of interpreting significant statistical interactions and main effects in a multivariate design when tests were conducted under natural conditions.

Fox, J.L. and M.S. Moyer. 1975. Effect of power plant chlorination on estuarine productivity. Chesapeake Science 16(1): 66-68.

Power plants chlorinate their cooling water to prevent biological fouling of condenser tube walls. The authors studied the effects of chlorine on in site net primary production in the discharge waters of a power plant at Crystal River, Florida. Primary production values decreased an average of 57% due to plant passage and chlorination. In the absence of chlorine, the average decrease was 13%.

Galya, D., M. Scherer, J. Herberich, S. Kelly and J. Scheffer. 2004. Assessment of power plant entrainment in comparison to long-shore ichthyoplankton transport. Flatfish Biology Conference 2004, Westbrook, CT (USA), 1-2 Dec 2004.

No abstract.

Galtsoff, P.S. 1946. Reaction of oysters to chlorination. Report No. 11, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, DC.

No abstract.

Gaudy, R. and B. Moatti. 1978. Study of the mortality of zooplankton transient in the cooling waters of a thermoelectric power plant. Symposium on Pollution of the Mediterranean, Antalya, Turkey.

The mortality of zooplankton sampled from intake and effluent circuits of a power plant (Martigues-Ponteau, Gulf of Fos, France) has been followed during a 18 months study. A vital staining technique was used to determine the proportion of dead and live animals under different conditions of power plant activity. The sampling process, added to the natural mortality caused a mortality rate of 25%. The lethal factors introduced by the cooling water system were: turbulence (mechanical shock in the circuits) 21%; thermal shock, whose effect is correlated with the increase of t (about 0 to 12%) and chlorination (31% average). The mortality appeared to affect larger and smaller forms of zooplankton equally. These results are discussed and compared with previous estimations.

Gavaskar, A.R. and A.S.C. Chen. 2002. Proceedings of the third international conference on remediation of chlorinated and recalcitrant compounds. Monterey, CA, May 2002. ISBN: 1-57477-132-9. Compact disc available for $295 from Battelle, 505 King Ave., Columbus, OH 43201-2693.

The Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds (May 2002) was attended by approximately 1,450 scientists, engineers, regulators, remediation site owners, and other environmental professionals representing universities, government site management and regulatory agencies, and R&D and manufacturing firms from 36 countries.

The 320 papers in this proceedings address the challenge of characterizing, remediating, monitoring, and closing sites contaminated with chlorinated solvents and other recalcitrant compounds. At sites with these contaminants, many factors can challenge the technical effectiveness and economics of the remedial action. Papers in the Remediation Project Planning and Site Characterization section discuss regulatory interaction (e.g., Risk-Based Corrective Action [RBCA]) and describe approaches for design and modeling of remediation projects, selection and use of data management tools, and site characterization methods for a wide range of media and contaminants, determination of achievable cleanup goals, and remedy selection/design. The Remediation Technologies section contains information on selecting from the spectrum of remediation technologies-physical, biological, chemical, thermal, natural attenuation, and combined-and methods of delivering the chosen treatment technology to the contaminants effectively and economically and ways to monitor the progress of the remediation. Post-Remediation Strategies presents ways to accomplish the monitoring necessary to determine the achievement of short-term performance endpoints that meet regulatory and economic goals. Also addressed are design and implementation of short-term exit strategies and long-term monitoring programs.

Gavaskar, A.R. and A.S.C. Chen. 2005. Proceedings of the fourth international conference on remediation of chlorinated and recalcitrant compounds. Monterey, CA, May 2004. ISBN: 1-57477-145-0. Compact disc available for $295 from Battelle, 505 King Ave., Columbus, OH 43201-2693.

The Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds (May 2004) was attended by approximately 1,425 scientists, engineers, regulators, remediation site owners, and other environmental professionals representing universities, government site management and regulatory agencies, and R&D and manufacturing firms from 26 countries.

This proceeding consists of 682 documents, representing essentially all platform talks and poster presentations made at the Conference. The 322 papers and 360 abstracts address the challenge of characterizing, remediating, monitoring, and closing sites contaminated with chlorinated solvents and other recalcitrant compounds. Among the topics covered are chlorinated solvent plumes, DNAPL, arsenic, mercury, MTBE, perchlorate, energetics, PCBs, and PAHs in groundwater, soil, fractured bedrock, and sediments. New developments in site characterization and remediation technologies, such as permeable barriers, chemical oxidation, thermal treatment, biological remedies, and natural attenuation are addressed.

The papers and abstracts are organized into the following sections:
Site Assessment and Characterization
DNAPL Source Remediation Technologies
Solvent Plume Control and Treatment Technologies
Remediation of Other Recalcitrant Compounds and Matrices
Managing the Remediation and Post-Remediation Process.

Gentile, J.H., J. Cardin, M. Johnson and S. Sosnowski. 1976. Power plants, chlorine, and estuaries Ecol. Research Series U.S. Environmental Protection Agency 76-055: 37.

Biological assay systems using indigenous holo- and meroplankton were designed to model the chlorination patterns of power plants. A matrix of chlorine concns and exposure patterns permitted the generation of response isopleths that were then applied to developing design criteria. The marine phytoplankter, *Thalassiosira pseudonana* showed

a 50% reduction in photosynthesis when exposed to 0.15 ppm Cl_2 for 10 minutes, and complete growth inhibition after 5 minutes exposure to 0.3 ppm. Microzooplankton adults were somewhat less sensitive in that a 5 minute exposure at 2.5 ppm was necessary to produce 50% mortality. Larval and juvenile fish were sensitive to chlorine levels ≤ 0.2 ppm for exposure periods of 60 to 90 minutes. 2 field studies were evaluated and compared to lab data with specific emphasis on the use of ATP to monitor entrainment and damages. A review of pertinent literature is also included.

Gibson, C., F. Tone, P. Wilkinson, J. Blaylock and R. Schirmer. 1981. Toxicity, bioaccumulation and depuration of bromoform in five marine species: *Protothaca stamineae*', (littleneck clam), *Mercenaria mercenaria*, (eastern hard clam), quahog, *Crassostrea virginica*, (eastern oyster), *Penaeus aztecus*, (brown shrimp), *Brevoortia tyrannus*, (Atlantic menhaden). Government Reports Announcements. Battelle, Richland, WA, Pacific Northwest Lab Report. 53 pp.

Bromoform has been identified as the single most abundant halogenated organic compound produced by the chlorination of marine waters. To determine the potential Biological effects of its release into marine waters, short-term toxicity bioassay and 28-day uptake/28-day depuration studies were conducted with five marine species: *Protothaca staminea*, *Mercenaria mercenaria*, *Crassostrea virginica*, *Penaeus aztecus*, and *Brevoortia tyrannus*. These species have commercial and economic importance and are often found in the vicinity of discharge streams from nuclear fueled steam electric stations.

Gibson, C.I., T.O. Thatcher and C.W. Apts. 1976. Some effects of temperature, chlorine, and copper on the survival and growth of the coon stripe shrimp. Thermal Ecology Vol 2: 88-92.

Bioassay and growth-rate experiments were conducted on coon stripe shrimp to determine the LL_{50} value for heat and the LC_{50} values for chlorine and copper, and the effect of sublethal concentrations of these materials on the growth rate of the shrimp. Critical Thermal Maximum (CTM) values were found to increase with an increase in size and rate at which the temperature was elevated. Shrimp were more resistant to chlorine when acclimated and exposed at 8-10°C than when acclimated at 8°C and exposed at 15 or 20°C or when acclimated and exposed at 15°C. Optimal growing temperature for periods up to one month was 16°C. Copper concentrations of 0.041 mg/L effectively retarded the growth at 16°C over a 1-month period. Chlorine concentrations of 0.18 mg/L were lethal at 16°C and reduced growth of the shrimp at 0.08 mg/L over a 1-month period. (See also W77-05541)

"Gift's Bioassy Work". 1973. Appendices Vol. IV, Sect. IIIA in Environmental Report, Indian Point No. 3. Consolidated Edison Co. of New York, Inc., New York, NY.

No abstract.

Ginn, T.C. and J.M. O' Connor. 1978. Response of the estuarine amphipod *Gammarus daiberi* to chlorinated power plant effluent. Estuarine Coastal and Shelf Science 6(5): 459-469.

The amphipod *G. daiberi* was subjected to plume drifts and laboratory exposures to chlorinated power plant cooling water effluent. Behavioral reactions to unchlorinated and chlorinated effluent were examined in an avoidance trough. During plant chlorination, the amphipods survived 1-h exposures to full-strength cooling water effluent (ΔT = 7.3-9.3°C, 0.05 ml^{-1} total chlorine). Test groups of *G. daiberi* drifted through the discharge plume during chlorination displayed no increased immediate or latent mortalities. One-hour static bioassays revealed an initial TL_{50} value of 1.85 mg/L total chlorine, which decayed to 0.2-0.5 mg/L during the exposure period. At ambient temperatures of 26.4-26.6°C, the amphipods avoided unchlorinated effluent at ΔT's>3.3°C. At lower ambient temperatures (15.3-15.7°C), no avoidance was observed at a 7.1°C ΔT. Chlorinated discharge water was avoided by *G. daiberi* at both ambient temperatures.

Ginn, T.C., W.T. Waller and G.J. Lauer. 1974. The effects of power plant condenser cooling water entrainment on the amphipod, *Gammarus* sp. Water Research 8: 937-945.

The abundant Hudson River amphipod *Gammarus* sp. was examined for viability before and during entrainment in the Indian Point cooling water system. The mean percent survivial of *Gammarus* sp. sampled during ΔT's of 7.1–8.3°C and ambient temperatures of 24.9–26.0°C was 98.5 and 97.4% for the two intake stations and 90.1 and 96.8% for the discharge canal stations D-1 and D-2 respectively. A statistically significant (α = 0.05) difference was detected between the survival of *Gammarus* sp. at the intake stations and discharge station D-1, located near the upper end of the discharge canal. Entrained *Gammarus* sp. experience increased initial and latent mortalities during periods of condenser chlorination. Comparison of the abundances of entrained *Gammarus* sp. during day and night sampling periods reveals a significantly higher occurrence during darkness. Temperature bioassays indicate that the thermal tolerance of *Gammarus* sp. is dependent on exposure time and ambient temperature. The temperature resulting in a 50% mortality of *Gammarus* sp. for 30 minutes exposure times increased approximately 11°C as ambient temperatures increased from 2.5 to 25.8°C. Consequently, *Gammarus* sp. was capable of surviving ΔT's of greater magnitude as the ambient temperature to which they were acclimated decreased. Temperature bioassays indicated that *Gammarus* sp. should be able to tolerate all projected time-temperature exposure combinations encountered during entrainment through the cooling water system.

Goldman, J.C. 1978. Combined toxicity effects of chlorine, ammonia, and temperature on marine plankton. Progress report, November 1976-31 January 1978. COO-2532-3 DOE Contract Number EY-76-S-02-2532 W.H.O. Institution. Woods Hole, MA (USA), Woods Hole Oceanographic Institution Report. 6 pp.

Studies on the effects of chlorine, chloramines, and temperature on marine plankton have been carried out for three years. Species studied include marine phytoplankton, lobster larvae (*Homarus americanus*), oyster larvae (*Crassostrea virginica*), copepods (*Acartia tonsa*), rotifers (*Brachionas plicatilis*), grass shrimp (*Palamonetes pugio*) summer flounder larvae (*Paralichthys dentatus*), larval and juvenile killifish (*Fundulus heteroclitus*), juvenile scup (*Stenotomus versicolor*), and juvenile winter flounder (*Pseudopleuronectes americanus*). In addition extensive studies on chlorine chemistry in seawater have been carried out. The major conclusions are that entrainment effects on permanent plankton such as phytoplankton, copepods, and rotifers are temporary, that is those organisms surviving chlorination and temperature shocks are capable of renewed and unrestricted growth once returned to the receiving water. Because chlorine is only applied for short periods daily in most power plants, the total population of the above organisms actually exposed to chlorine is small and the effects may be hardly measurable in receiving waters. However, chlorination effects on larval species that spawn intermittently could be catastrophic. In addition, there are many unanswered questions regarding the fate of chlorine that is dissipated in marine waters. Are the losses real and, if so, do they pose a toxicity threat to marine biota.

Goldman, J.C. and J.A. Davidson. 1977. Physical model of phytoplankton mortality at coastal power plants. Environmental Science and Technology 11(9): 908-913.

A physical model of the impact of coastal power plant chlorination on marine phytoplankton was developed. Several steady state biomass levels of the test alga *Phaeodactylum tricornutum* were established in continuous cultures by varying the concentration of P in the growth medium. The algae were then exposed to combinations of chlorine and temperature stress for 1 h, and deviations from the prestress steady state were observed over long periods of time. Three types of response occurred that were a function of the applied chlorine/biomass ratio: no effect, effect followed by recovery, and complete washout. It is suggested from the results that, given the typical organic loads present in coastal waters, excessive levels of chlorine may be in current use, and that the effects on entrained phytoplankton probably have little bearing on the ultimate effect on the standing crop in the receiving water. The most important considerations were the hydrologic, Biological and chemical qualities of the receiving waters themselves.

Goldman, J.C. and H. Quinby. 1979. Phytoplankton recovery after power plant entrainment. Journal Water Pollution Control Federation 51(7): 200-206.

Natural populations of marine phytoplankton from the intake and discharge stations of 2 coastal power plants in southeastern Massachusetts [USA] all demonstrated the same degree of recovery when grown in continuous cultures with a defined artificial seawater medium. Neither populations exposed to elevated temperatures nor those subject to chlorination and heat treatment showed any adverse permanent effects. The flora of phytoplankton species dominating in samples for a particular experiment were consistently similar, indicating that alterations in the composition of phytoplankton species in receiving waters may be hardly measurable. Entrainment effects on both phyto- and permanent zooplankton populations in receiving waters, because of their relatively rapid generation periods, are probably minor compared with the potentially major effects on larval plankton that spawn intermittently.

Goldman, J.C., J.M. Capuzzo and G.T. Wong. 1978. Biological and chemical effects of chlorination at coastal power plants. Pp. 291-305. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects. Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Graslund, S., P.A. Bergqvist and B.E. Bengtsson. 1999. Potential formation of toxic by-products from the use of chlorine as a disinfectant in intensive shrimp farming in Southeast Asia. Fourth Symposium on Diseases in Asian Aquaculture: Aquatic Animal Health for Sustainability. Cebu International Convention Center, Waterfront Cebu City Hotel, Cebu City, Philippines, Asian Fisheries Society, Manila (Philippines) Fish Health Section. 12 pp.

The purpose of this study was to elucidate whether halogenated hydrocarbons are formed as a side effect following chlorination of shrimp ponds, and to see if these by-products might cause toxicity to biota. Disinfection of shrimp ponds by application of chlorine is widely recommended as a disease preventing measure in intensive shrimp farming in South East Asia. In Thailand alone there is an estimated 50,000 tons of chlorine annually used in shrimp farms. The fate of chlorinated substances in shrimp ponds is not known until now. On the contrary chlorination of drinking water has been subject to many studies. These generally show that chlorine added to natural waters react with organic substances and result in significant concentrations of halogenated hydrocarbons. Several of these substances are known to be toxic to aquatic organisms or humans. An experiment was conducted in experimental ponds set up as a controlled model of shrimp ponds, i.e., filled with sediment and salt water. The ponds were treated with calcium hypochlorite at doses ranging from normal dose to 150 times the normal rate. Black tiger shrimp, *Penaeus monodon*, were put in each pond 4 days after chlorination. Sampling for analyzes was made from water, air, sediment and shrimp. Passive sampling with semi-permeable membrane devices (SPMDs) was made in the pond water and in the air close to the water surface during a period of 12 days with start just before chlorination. Simultaneously, passive sampling was terminated and shrimp and sediment were collected. SPMD samples were prepared for analysis by dialysis. The lipophilic phase was extracted from shrimp hepatopancreas and sediment. Each sample was run through a GPC in a HPLC in order to fractionate the sample content. The fraction of the size of diethylhexylphtalate and smaller was collected. This fraction was run in a GC/ECD in order to detect halogenated hydrocarbons. Part of the same fraction was tested for toxicity in Microtox assays. Results of the substances contained in the samples and their toxicity in Microtox assays will be presented at the symposium. Whether there is a correlation between occurrence of halogenated organic compounds and toxicity seen in Microtox assays will be answered, as well as the question of how the formed substances are distributed in different compartments of the system - water, sediment, air and shrimp.

Gullens, S.R., R.M. Block, J.C. Rhoderick, D.T. Burton and L.H. Liden. 1977. Effects of continuous chlorination on white perch (*Morone americana*) and Atlantic menhaden (*Brevoortia tyrannus*) at two temperatures. Research Association Southeastern Biologists Bulletin 24: 55 pp.

No abstract.

Haag, W.R. 1981. Chemistry of saline-water chlorination. Oak Ridge National Lab and Tennessee Univ., Knoxville, TN (USA). 160 pp.

Vast quantities of natural waters are used by power plants for cooling purposes. This water is chlorinated to prevent slime build-up inside the cooling pipes, is circulated through the cooling system, and eventually discharged back into the water body. In order to assess the environmental impact of water chlorination, it is necessary to know what chemical compounds are produced and discharged into the receiving waters. To attack this problem, a review of the present state of knowledge of natural water chlorination chemistry was performed, and some experimental work explained the results of previous workers by showing that chlorine losses at very high doses in seawater are simply the result of chlorate and bromate formation which, however, is negligible at normal doses. The most important chlorine-produced oxidants, along with the relevant chemical reactions, were chosen as a basis for a kinetic model of saline water chlorination chemistry. Kinetic data were compiled in a computer program which simultaneously solves 24 differential equations, one for each species modeled. Estimates were made for the unknown rate constants. A purely predictive model was not possible due to the great variability in the organic demand; however, the model is applicable under a broad variety of conditions (except sunlight), and it provides a reasonably good description of a halamine chemistry under environmental conditions.

Hall, L.W., Jr., D.T. Burton and S.L. Margrey. 1979a. Chlorine, temperature and exposure duration efects of power plant effluents on juvenile blue crabs *Callinectes sapidus* and grass shrimp, *Palaemonetes pugio*. Journal of Toxicology Environmental Health 5: 749-757.

Effects of interacting Cl, temperature and exposure conditions similar to those found in power plant effluents were assessed for blue crab *C. sapidus* and grass shrimp *P. pugio*. Test organisms were exposed to total residual Cl (TRC) concentrations of 0.00, 0.15 and 0.30 mg/L in combination with temperatures 2, 6 and 10°C above ambient for 0.08, 2.0 and 4.0 h. TRC concentrations decayed over 1-1.5 h to < 0.01 mg/L. Temperatures decayed over 4 h to 2°C above ambient. These conditions were used to simulate Cl and temperature conditions in power plant discharge canals and near-field receiving streams. Regression model techniques were used to establish interaction of Cl, temperature excess (ΔT) and exposure duration as factors causing death up to 36 h after exposure. Mortality increased for grass shrimp as Cl concentration, ΔT, and exposure length increased. A percentage mortality model for grass shrimp shows that response to Cl concentration alone and ΔT alone is proportional to the square root of Cl concentration and ΔT, the effect of exposure duration is linear, and no 2nd-order interactions occurred among variables tested. No significantly mortality was found for blue crabs for any variable tested.

Hall, L.W., Jr., D.T. Burton and S.L. Margrey. 1979b. The effects of chlorine, elevated temperature and exposure duration of power plant effluents on larval white perch, *Morone americana*. Water Resources Bulletin 15: 1365-1373.

No abstract.

Hall, L.W., Jr., D.T. Burton and S.L. Margrey. 1979c. The influence of acclimation temperature on the interactions of chlorine, elevated temperature, and exposure duration for grass shrimp, *Palaemonetes pugio*. Transnational American Fish. Society 108: 626-631.

The effect of 15 and 27°C acclimation temperatures on interactions of Cl, elevated temperature (ΔT), and exposure duration was assessed for the grass shrimp. Test organisms were exposed to total residual Cl (TRC) concentrations of 0.00, 0.15 and 0.30 mg/L in combination with ΔT of 2, 6 and 10°C above acclimation temperature and exposure periods of 0.08, 2.0 and 4.0 h. Cl concentrations were decayed over a 1-1.5 h period to < 0.01 mg/L TRC and temperatures were decayed over 4 h to 2°C above acclimation. Mortality observations were conducted for 96 h. Most of the deaths occurred 36 h after exposure to the 3 test variables. A percent mortality model for grass shrimp acclimated to 27°C showed that the response to Cl concentration alone and ΔT alone was proportional to the square root of either variable; the exposure duration effect was linear; and no 2nd-order interactions occurred among the variables tested. The model for grass shrimp acclimated to 15°C showed that ΔT had no effect; the response to Cl concentration was the dominant factor; and there existed a 2-way linear interaction between Cl concentration and exposure duration.

Hall, L.W., Jr., D.T. Burton and S. Margrey. 1981a. Acclimation temperature: an important factor in power plant chlorination studies with larval white perch, *Morone americana*. Journal of Toxicology and Environmental Health 7(6): 941-50.

Larval white perch were subjected to interacting power plant conditions of total residual chlorine (0.00-0.30 mg/L), elevated temperature (2, 6, and 10°C), and exposure time (0.08, 2.0, and 4.0 h) at acclimation temperatures of 15 and 23°C. Mortality observations were conducted up to 96 h after exposure. Acclimation temperature was a significant factor contributing to the effects of simulated power plant conditions during the low and high thermal conditions. Larvae tested at 23°C generally showed greater mortality at all treatment levels than those tested at 15°C. Mortality of test organisms during a 4-h exposure at the higher acclimation temperature was greater than 85% at elevated temperatures greater than 6°C regardless of other treatment factors. Mortalities as low as 30% were observed at the lower acclimation temperature.

Hall, L.W., Jr., D.T. Burton, S.L. Margrey and K.R. Dixon. 1981b. Time-related mortality responses of striped bass (*Morone saxatilis*) ichthyoplankton after exposure to simulated power plant chlorination conditions. Water Research 15(7): 903-910.

Time related mortality responses of striped bass eggs and prolarvae were evaluated after exposure to interacting total residual chlorine (TRC), ΔT and exposure time representing condenser entrainment and effluent discharge conditions. Mortality observations were conducted at unequal time intervals for 36-h after exposure to the test conditions. A non-linear least square regression model was separately fit to the cumulative mortality data for both eggs and prolarvae. Analysis of the immediate mortality response (death at time 0) of both eggs and prolarvae showed no significant effects of ΔT or interactions between ΔT and the other variables; however, only a few hours after exposure ΔT does have a significant effect on the mortality response.

Hall, L.W., Jr, G. Helz and D.T. Burton. 1981c. Power-plant chlorination: A Biological and chemical assessment. REPRI EA-1750 (Res Proj. 1312-1) Electric Power Research Insitute, 3412 Hillview Ave., Palo Alto, CA 94303. Final Report, December 1981. Prepared by the Academy of Natural Sciences of Philadelphia, 252 pp.

An assessment is presented of the pertinent literature on chlorine chemistry and toxicity and a listing of research recommendations based on the review. Chlorine reaction rates and paths, chemical species, oxidant analyses, and organic products are discussed. Freshwater, estuarine, and marine toxicity methodologies are considered as well as specific tests on many organisms. Research recommendations include refinement of existing methodologies and development of new techniques. (ERA citation 07:044733)

Hall, L.W., Jr., D.T. Burton and L.H. Liden. 1982. Power plant chlorination effects on estuarine and marine organisms. Critical Reviews in Toxicology. 10(1): 27-48.

The objectives of this review were to collect, synthesize and interpret phytoplankton, zooplankton, macroinvertebrate and fish chlorine toxicity data related to biofouling control in estuarine and marine thermoelectric power plants, and to identify deficiencies in available information in order to recommend future research concerning the ecological effects of power plant cooling water chlorination. Chlorine toxicity data and subsequent chlorine species as reported by the various investigators are presented in this review.

Hamilton, D.H.J., D.A. Flemer, C.W. Keefe and J.A. Mihursky. 1970. Power plants: effects of chlorination on estuarine primary production. Science (NY) 169(3941): 197-198.

Steam electric stations may reduce primary production of cooling water by 91% as a result of chlorine applications for control of fouling organisms. Bacterial densities and concs of chlorophyll a are also reduced. Slight stimulation of production may occur in the absence of chlorination. Based on the available supply of 'new' water, a maximum loss of primary production of 6.6% was calculated for the tidal segment of the Patuxent River adjacent to a steam electric station.

Harwood, M., C. Blaise and P. Couture. 1989. Algal interactions with the genotoxic activity of selected chemicals and complex liquid samples. Aquatic Toxicology 14(3): 263-276.

Ultra-acute 4-h algal interaction experiments on the genotoxic activity of three chemicals (MNNG, 4NQO and 2AA) and 9 complex liquid samples (4 organic chemical manufacturing effluents, 2 associated intake water supplies, 2 inorganic manufacturing effluents, and 1 pulp and paper effluent) were undertaken with *Selenastrum capricornutum*. Genotoxic activity was determined with the SOS Chromotest on each pre-exposure test solution and on each post-exposure supernatant and algal cell extract. Responses with the chemicals ranged from no activity change for MNNG to detoxication for 4NQO and to detoxication/uptake for 2AA. Exposure to experimental light and centrifugation were also shown to have a significant effect in reducing the activity of 2AA. All but one of the complex liquid samples proved to be genotoxic and exposure responses were varied. As well as effects noted for the chemicals, increased genotoxic potency was observed in 3 samples, suggesting the presence of pro-mutagens capable of being activated by algal metabolism. Our results indicate that phytoplankton could play an important positive (detoxication) or negative (activation, uptake) role in its interactions with genotoxicants present in complex liquid wastes discharged to the aquatic environment.

Heinle, D.R. 1973. Effects of the Chalk Point Power Plant on pumped and entrained copepods, August 12, 1971 and May 16, 1972, with notes on the Vienna Generating Station. NRI Ref No. 73-74. College Park, MD: University of Maryland, Natural Resources Institute.

The rate of C 14-uptake, an index of photosynthetic rate, and the concentration of chlorophyll a, a measure of standing crop, were measured to estimate the effects of entrainment on phytoplankton. The rate of carbon assimilation appeared to depend on the ambient water temperature and the temperature rise experienced by the entrained organisms. It was concluded that the reduction in carbon assimilation was greater than could be explained by the effects of mechanical and thermal stress and that chlorine was an important factor in the reduction.

Heinle, D.R. 1976. Effects of passage through power plant cooling systems on estuarine copepods. Environmental Pollution. 11: 39-58.

The effects of chlorination, heated water, and entrainment on the copepods *Scottolana canadensis*, *Eurytemora affinis* and *Acartia tonsa*, at three power plant sites in Chesapeake Bay were measured by vital staining, a technique that allowed the examination of more individual organisms for viability or mortality. The Vienna plant (located at the Nanticoke River) with the greatest temperature rise, highest absolute temperatures, lowest salinities, and no chlorination, caused no detectable mortalities. At the Clark Point plant (located on the Patuxent River) there were slight mortalities with no chlorination and substantial mortalities occurred only during chlorination. At the

Morgantown site (located in Maryland below the Route 301 bridge across the Potomac River estuary) significant mortalities occurred only when chlorine was used. In addition to the slight mortalities caused by temperature alone and the clear effects of chlorine, the data suggested a difference in sensitivity of the three species. In order of increasing sensitivity they are: *S. canadensis, E affinis* and *A. tonsa*. The statistical problems associated with precise estimates of numbers of organisms passing through the Morgantown plant are presumed to be due to inadequate sampling efforts and the lack of prior knowledge of the copepod distribution.

Heinle, D.R. and M.S. Beaven. 1977. Effects of chlorine on the copepod *Acartia tonsa*. Chesapeake Science 18: 140.

The authors found LC_{50}'s of 0.175, 0.062, 0.028 mg/L of chlorine produced oxidants for adult and immature copepods (combined) of *A. tonsa* at 15°C and salinities of 10.4 to 11.8 ppt. Preliminary results with nauplii of *A. tonsa* suggest lower LC_{50}'s than those for adults at equivalent exposure times. Comparison of all of the available published and unpublished results for adults of *A. tonsa* suggest that the relationship between log LC_{50} and log time to 50% mortality are linearly related in spite of considerable variation in methods used by various investigators. As near-field concns of chlorine of 0.001 to 0.01 mg/L have been estimated adjacent to a power plant on an estuary and as high as 2 mg/L near sewage treatment plants discharging into estuarine waters, it is suggested that lethal exposures to chlorine might commonly occur.

Heinle, D.R., H.S. Millsaps, Jr. and C.V. Millsaps. 1974. Zooplankton studies Morgantown. Pp. 157-161. In: L.D. Jensen (ed). Proceedings of Second Workshop on Entrainment and Intake Screening. Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD

No abstract.

Hergott, S. 1977. Chlorinated compounds in coastal power plant cooling waters. Chesapeake Science 18(1): 119-128.

Results are presented based on 4 months of a 12 month study funded by EPA of chlorination practices at 5 coastal power plants in California. Typical cooling water system layout is discussed with special emphasis on chlorination procedure Halogen residuals are measured at the condenser inlet and this measured residual is the criterion for determining the chlorine injection rate. Variations among the power plants occur as to frequency and duration of chlorination, dosage, analytical methods and equipment. Field studies at 3 of the 5 power plants are discussed. Cooling water is sampled during chlorination cycle at 2 locations simultaneously and halogen residuals (tree and/or total) measured at approximately 2 minute intervals. Halogen residuals are determined amperometrically using Fisher and Porter titrators (Model 17T1010). Water samples are brought back to the laboratory for determinations of ammonia-nitrogen, total nitrogen, soluble nitrogen, chloride, bromide, and suspended solids. The chlorine dose is calculated from the chlorine injection rate and the cooling water flow-rate. Decay studies

are performed at the outfall to determine the persistence of the halogen residual. Results are given as graphs showing the temporal variation of the halogen residual during the chlorination cycle at various sampling points in the system. Explanations of the observed decay patterns are suggested in relation to water quality, tidal influences, and/or chlorination practices.

Hergott, S.J., D. Jenkins, and J.F. Thomas. 1978. Power plant cooling water chlorination in northern California. Journal of Water Pollution Control Federation 50(11): 2590-2601.

The nature, levels, and persistence of chlorinated compounds in the discharges of five power plants in northern California are determined. Chlorination frequency varies among the plants. All effluents produce receiving water oxidant residual levels predicted to be chronically toxic to marine organisms. Receiving water from two plants shows levels predicted to be chronically toxic to freshwater organisms. Acutely toxic levels exist in the receiving waters at one site.

Hinchee, R.E. 1998. First international conference on remediation of chlorinated and recalcitrant compounds. Monterey, CA, May 1998. ISBN: 1-57477-062-4. Six vol. set available for $349.50 from Battelle, 505 King Ave., Columbus, OH 43201-2693.

Restoration of sites contaminated by chlorinated and other recalcitrant compounds is the subject of increasing attention worldwide. The 1998 International Conference on Remediation of Chlorinated and Recalcitrant Compounds (held in Monterey California, May 18-21, 1998) was the first in a series of biennial conferences focusing on the more problematic substances-chlorinated solvents, pesticides/herbicides, PCBs/dioxins, MTBE, DNAPLs, and explosive residues-in all media. Physical, chemical, biological, thermal, and combined technologies for dealing with these compounds were discussed, along with natural attenuation, site characterization, and monitoring technologies. Pilot- and field-scale studies were presented, along with supporting laboratory data. Several sessions focused on human health and ecological risk assessment, regulatory issues, technology acceptance, and resource allocation and cost issues.

The Conference was attended by scientists, engineers, managers, consultants, and other environmental professionals representing universities, government, site management and regulatory agencies, remediation companies, and research and development firms from around the world. Approximately 550 platform and poster papers were presented.

Risk, Resource, and Regulatory Issues: Remediation of Chlorinated and Recalcitrant Compounds (C1-1). Nonaqueous-Phase Liquids: Remediation of Chlorinated and Recalcitrant Compounds (C1-2). Natural Attenuation: Chlorinated and Recalcitrant Compounds (C1-3). Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds (C1-4). Physical, Chemical, and Thermal Technologies: Remediation of Chlorinated and Recalcitrant Compounds (C1-5). Designing and Applying Treatment Technologies: Remediation of Chlorinated and Recalcitrant Compounds (C1-6).

Hirayama, K. and R. Hirano. 1970. Influences of high temperatures and residual chlorine on marine phytoplankton. Marine Biology 7:205-213.

Marine phytoplankton forms are frequently exposed to sudden biological changes such as rapid rise in water temperature and chlorine content of their environment, resulting from the use of sea water for cooling purposes by electric generators. The direct influence of these effluents, i.e., inhibitory effects of high temperature and residual chlorine on growth and photosynthesis of *Chlamydomonas* sp. and *Skeletonema costatum*, were investigated experimentally. *Chlamydomonas* sp. and *S. costatum* exposed to high temperatures were affected in their growth from 43° and 35°C, respectively, by immersion of the respective cultures in a warm bath for 10 minutes. Treatment at high temperatures of 40 °C and 30° ∼35°C for 10 minutes, influenced their photosynthetic activities, which were completely inhibited immediately after 10 minutes exposure at 42° and 37 °C, respectively. *S. costatum* was killed by chlorine at a concentration of 1.5 ∼2.3 ppm when exposed for exactly 5 or 10 minutes, while *Chlamydomonas* sp. was not irreversibly damaged even at 20 ppm chlorine or more with the same exposure period. These results lead to the conclusion that the high temperature of, and residual chlorine in, effuents from a power plant discharging into the open sea, should not cause great damage to marine phytoplankton in that area.

Hoepner, T. and S. Lattemann. 2003. Chemical impacts from seawater desalination plants-- a case study of the northern Red Sea. Desalination 152(1-3): 133-140.

Seawater desalination facilities range from heavy coastal industry to small local plants, with the majority being either thermal multi-stage flash (MSF) or membrane-based reverse osmosis (RO) plants. Irrespective of the process, pretreatment chemicals are added to the intake water to improve plant performance. Furthermore, corrosion cannot be entirely prevented and heavy metals add to the chemical load of the brines, which are discharged to the marine environment. For impact assessment, information about chemical loads as well as the sensitivity of the impacted ecosystem is required. Loads of selected chemicals were estimated for 21 plant locations in the Red Sea including the Gulf of Aqaba and Gulf of Suez. Locations were identified from the 2000 IDA Worldwide Desalting Plants Inventory Report and localized on GIS data maps from the World Conservation Monitoring Center (WCMC). Their combined capacity exceeds 1.5 million m/d, with approximately 1.2 million m/d from MSF and 0.38 million m/d from RO plants. Based on these figures, the daily chemical discharge amounts to 2,708 kg chlorine, 36 kg copper and 9,478 kg antiscalants, when effluent concentrations of 0.25 ppm, 0.015 ppm and 2 ppm are assumed, respectively. The sensitivity of the Red Sea and the Gulf of Aqaba to chemical loads is discussed and comparisons to the Arabian Gulf and the Mediterranean Sea are drawn.

Holland, G.A., J.E. Laster, E.D. Neumann and W.E. Eldridge. 1960. Toxic effects of organic and inorganic pollutants on young salmon and trout. Research Bulletin No. 5, Department of Fisheries, State of Washington, Olympia, WA.

No abstract.

Holmes, N.J. 1969. The suppression of mussel fouling by chlorination. Symposium on Marine Biology, Research Lab Memorandum No. RD/L/M 269. Central Electricity Research Lab, Leatherhead, England. Pp. 35-38.

No abstract.

Hose, J.E., T.D. King and J.S. Stephens, Jr. 1984. Effects of dechlorinated seawater on fish behavior. Marine Environmental Research. 11(1): 67-76.

Behavioral responses to chemically dechlorinated seawater were studied using 2 species of marine fish associated with power plant discharge areas off Southern California. Opaleye (*Girella nigricans*) neither avoided nor were attracted to chlorinated seawater containing 0 multiplied by l mg/L total residual oxidants (TRO) which had been dechlorinated using equimolar or excess sodium thiosulfate. Blue-banded goby (*Lythrypnus dalli*) did not avoid dechlorinated seawater initially containing 0 multiplied by 1 or 0 multiplied by 9-1 multiplied by 0 mg/L TRO. Elimination of chlorine-produced oxidants by thiosulphate dechlorination resulted in 100% survival in both species. The toxicological implications of exposure to dechlorinated seawater are discussed.

Hose, J., E., D. Di Fiore, H.S. Parker and T. Scarerrotta. 1989. Toxicity of chlorine dioxide to early life stages of marine organisms. Bulletin of Environmental Contamination and Toxicology 42(3): 315-319.

No information exists on chlorine toxicity to marine organisms. This study sought to obtain information on chlorine dioxide toxicity using an exposure schedule typical of generating stations which discharge into the marine environment. Early life history stages of a plant, invertebrate and fish were tested since these stages are most sensitive to toxicants and are most likely to be exposed to the effluent.

Hoss, D.E., L.C. Coston, J.P. Baptist and D.W. Engel. 1975. Effects of temperature, copper and chlorine on fish during simulated entrainments in power plant condenser cooling systems. Pp. 519-527 in Environmental Effects of Cooling Systems at Nuclear Power Plants. Austria International Atomic Energy Agency, Vienna, Austria.

No abstract.

Hoss, D.E., L.C. Clements and D.R. Colby. 1977. Synergistic effects of exposure to temperature and chlorine on survival of young of the year estuarine fishes. Pp. 345-355. In: F.J Vernberg, A. Calbrese, F.P Thurberg and W.B. Verbberg (eds). Physiological Responses of Marine Biota to Pollutants. Academic Press, Inc., New York, NY.

No abstract.

Huang, J., L. Wang, N. Ren, L.X. Li, S.R. Fun and G. Yang. 1997. Disinfection effect of chlorine dioxide on viruses, algae and animal planktons in water. Water Research 31(3): 455-460.

In this paper, the disinfection effects of chlorine dioxide (ClO_2) on some main viruses, algae and animal planktons in water and the influence of ClO_2 on the inactivation of some microorganisms studied under various conditions such as the dose of disinfectant, contact time, and pH value, etc., were researched and reported. The effects and influence were compared with liquid chlorine, and results showed that the killing effect of ClO_2 on algae is about the same as or better than that of liquid chlorine and the inactivation effect of ClO_2 on viruses and animal planktons is more remarkable than that of liquid chlorine. The viruses were effectively killed off by ClO_2 in a wider pH range. Moreover, the mechanism of viruses killed by ClO_2 was tentatively investigated. Then, it is concluded that ClO_2 is an excellent disinfectant as a substitute for liquid chlorine.

Hughes, J.S. 1972. Acute toxicity of thirty chemicals to striped bass (*Morone saxatilis*). Paper presented at the Western Association of Game and Fish Commissioners. Salt Lake City, UT.

No abstract.

Hughes, J.S. 1975. Striped bass (*Morone saxatilis*) culture investigations in Louisiana with notes of sensitivity of fry and fingerlings to various chemicals. Louisiana Wildlife and Fisheries Commission, Baton Rouge, LA: Fish Bulletin No. 15.

No abstract.

Iyer, T.S.G. and P.R.G. Varma. 1994. Survival of *Listeria monocytogenes* in water subjected to different levels of chlorination. Fishery Technology. Society of Fisheries Technologists 31(1): 79-80.

The concentration of chlorine required to destroy all viable cells of *Listeria monocytogenes* present in the water used for seafood processing is studied. Based on these studies, it is recommended that the factories should chlorinate water supply to a reduced level of 10 ppm Cl_2 giving minimum contact time of 5 minutes.

James, W.G. 1966. Mussel fouling and the use of chlorine: Appendix I. In: Low Level Chlorination for the Control of Marine Fouling. Central Electricity Research Laboratories, Leatherhead, England.

No abstract.

Jenner, H.A., C.J.L. Taylor, M. Donk and M. Khalanski. 1997. Chlorination by-products in chlorinated cooling water of some European coastal power stations. Marine Environmental Research 43(4): 279-293.

Chlorination by-products (CBPs) are formed as a result of the chlorination of power station cooling water for anti-fouling purposes. Their production was studied at 10 coastal power stations in the UK, France and The Netherlands. Three categories of CBPs were determined: trihalomethanes; haloacetonitriles; and halophenols. Bromoform was the CBP most abundantly present in the effluents of all 10 power stations. At a mean chlorine dosage of 0.5-1.5mg/L (as Cl_2) the mean bromoform concentration was 16.32 plus or minus 2.10 µg/litre. The CBP found in second highest concentrations was dibromoacetonitrile (DBAN) with mean concentrations of 1.48 ± 0.56 µg/litre. Other CBPs detected were dibromochloromethane, bromodichloromethane and 2,4,6-trichlorophenol; concentrations of these three compounds were very low (<1 µg.litre). At those sites at which bromoform was measured in the dispersing effluent plume it was found to behave as a conservative parameter (significant direct correlation with plume ΔT).

Johnson, A.G., T.D. Williams and C.R. Arnold. 1977. Chlorine-induced mortality of eggs and larvae of spotted sea trout (*Cynoscion nebulosus)* Transnational American Fisheries. Society 106: 466-469.

No abstract.

Johnson, J.D., G.W. Inman, Jr. and T.W. Trofe. 1982. Cooling water chlorination: The kinetics of chlorine, bromine, and ammonia in sea water. Ncu/dese report. No pages.

The major inorganic reaction pathways for the chlorination of saline waters were measured by a variety of techniques including: (1) amperometric titration, (2) amperometric membrane covered electrode, (3) conventional kinetics methods for slow reactions, and (4) stopped-flow kinetics measurements with a micro-computer data acquisition system. The major reactions studied were: (1) the competitive reactions of ammonia and bromide ion with hypochlorous acid, (2) bromide oxidation by hypochlorous acid, (3) monochloramine formation in sea water, (4) monobromamine formation and subsequent disproportionation to form dibromamine, and (5) monochloramine oxidation of bromide to form bromochloramine. Reaction rates were determined in sodium chloride and sea water as a function of reactant concentration, pH, salinity, and ammonia concentration.

Johnson, J.D. and R.G. Qualls. 1983. Kinetic model for the chlorination of power plant cooling waters. Department of Environmental Sciences and Engineering. Chapel Hill (USA), North Carolina University Report: 89 pp.

Concern over the environmental effects of chlorination has prompted efforts to minimize the amount of chlorine necessary to prevent fouling of power-plant condensers. Kinetic expressions are developed for the short-term reactions of chlorine consumption by organic substances in natural freshwater. These expressions were developed to use in a kinetic model to predict the free and total available chlorine discharged in cooling water. This model uses commonly available water-quality data. It assumes that most of the chlorine-consuming substances are: (1) NH_3, (2) chloramine-forming organic-N, and

(3) humic substances. It uses the Morris-Wei model of chlorine-ammonia reactions. Chloramine formation from organic-N was represented by a model compound, glycylglycine.

Jolley, R.L. 1984. Basic issues in water chlorination: a chemical perspective Water Chlorination Conference, Williamsburg, VA, USA, Department of Energy Report: 32 pp.

Results from selected research papers published since the last conference (Asilomar, 1981) are reviewed and summarized. Although much progress has been made in developing predictive models for chlorination discharges, additional data are needed for reaction rates and mechanisms over a wider temperature range, especially for transformation and decomposition reactions of chlorine and chlorine-produced oxidants. Significant advances have also been made toward understanding the formation of trihalomethanes and the chlorination of humic materials, and toward identification of chlorination products in cooling waters, paper industry effluents, and wastewaters; however, because of the vast number of chlorination products, much remains unknown in this area. Further research is especially needed to expand our knowledge concerning products from the water chlorination treatment of food materials because only very limited information is available.

Junli, H., W. Li, R. Nanqi and M. Fang. 1994. Disinfection effect of chlorine dioxide on microorganism in water. Int. Conf. on Asian Water Technology '94, Raffles City (Singapore), 22-24 Nov 1994. No pagination.

In this paper, the disinfection effects of chlorine dioxide (ClO_2) on some main bacteria, viruses, algae and animal planktons in water were researched by numerous experiments. Simultaneously, the influence of ClO_2 on the inactivation of some microorganism was studied under various conditions such as the amount of the added disinfectant and the contact time, pH valve and other factors, and were compared with chlorine. The results showed that the inactivation effect of the ClO_2 on bacteria and algae is similar or more closely related to the chlorine, and the inactivation effect of ClO_2 on viruses and animal planktons is more remarkable than the chlorine. The bacteria and viruses were effectively killed off by using ClO_2 in a very wide range of pH value. Moreover, the investigation of the mechanism of killing bacteria and viruses by ClO_2 was tentatively undertaken. Then, we concluded that ClO_2 is a excellent disinfectant as substitute for the chlorine. This study is divided into two pieces of writing, with the first piece of writing dealing with the disinfection effect of ClO_2 on bacteria in water.

Karaas, P. 1992. Zooplankton entrainment at Swedish nuclear power plants. Marine Pollution Bulletin 24(1): 27-32.

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

Karande, A.A., S.N. Gaonkar, R. Viswanathan and A.K. Sriraman. 1982. Bioassay of antifoulant chlorine. Indian Journal of Marine Sciences 11(2): 177-179.

Laboratory bioassays were conducted using laboratory cultured, young settling stages as well as adults of major fouling species, with a view to determining suitable chlorine dosage and chlorination cycle to mitigate biofouling. Fairly high concentration of chlorine was required to cause death of the larvae. It was, however, possible to prevent settlement by desensitizing the larvae with low levels of residual chlorine. To remove fouling by adults was very difficult. Residual chlorine as high as 15-20 ppm for a period of 60 hr would be necessary to remove settled biofouling.

Ketelaars, H.A.M. and A.J. Wagenvoort. 1995. Control of *Dreissena* biofouling by the water storage corporation Brabantse Biesbosch. Aqua - Journal of Water Supply: Research and Technology 44 (1): 97-101.

Biofouling of intake, transport and distribution pipes can create major problems for the water industry, such as increased hydraulic resistance and energy costs, deterioration of taste and odour (decay of dead organisms) and promotion of bacterial regrowth and corrosion. The most notorious biofouling organism is the zebra mussel, *Dreissena polymorpha*. The Water Storage Corporation Brabantse Biesbosch (WBB) initially prevented *Dreissena* fouling by continuous chlorination of all intake and transport pipelines. After the discovery of undesirable disinfection byproducts (e.g., trihalomethanes) in the early 1970s, measures were taken to reduce the use of chlorine. The chlorine-dosing period was at first shortened by setting strict temperature limits, and since 1987 by restricting dosing to the growing season of *Dreissena* (occurrence of veliger larvae in zooplankton samples). In addition, other methods were used to reduce the total amount of chlorine. Chemical control of biofouling was terminated in places where the mussels could be removed easily by mechanical means. In some pipelines, flow rates turned out to be high enough to prevent biofouling, in others it sufficed to dose with chlorine intermittently. Another successful method was to create anoxic conditions in pipelines in order to remove the mussels. These control methods and the cessation of break-point chlorination resulted in a drop of the annual amount of chlorine used from 730 tonnes in 1974 to 51 tonnes in 1993.

Khalanski, M. and F. Bordet. 1978. Effects of chlorine on marine fauna. Journees de la Thermo-ecologie, Nantes (France), Nov 1979 Conference. No pagination.

In power plant cooling system, a seawater chlorination of 1 mg/L ClO^- is not enough to detach mussels and to prevent mussels fixation. The solution to protect pumping and cooling system should lead to an inhibition of mussels growth and a maintenance at a small size.

Khalanski, M. and R. Delesmont. 1994. Chlorine by-products in sea water at the Penly nuclear power plant. Measurement survey in May 1993. Electricite de France, Clamart, 51 pp.

The objective of the measurement survey conducted at the Penly nuclear power plant on May 27 and 28, 1993, was to determine the distribution of residual oxidants and volatile organo-halogenated compounds (THM) concentrations in the discharge plume when both units of the plants are carrying out chlorination. The data collected provide a mapping of the chemical types analyzed and will serve in calibration of a numerical model to simulate the evolution of these compounds in the discharge plume. During the two days of measurements, quantitative analyses were performed on samples taken by helicopter, once at high tide and twice at low tide with mean tidal coefficients. The chlorine injection level ranged from 0.84 to 0.92 mg/L (ppm) in unit 1 and from 0.64 to 0.70 mg/L in unit 2. Residual oxidants were measured as Total Chlorine Equivalents using the colorimetric DPD method. Bromoform accounted for 97.8 % of the THM generated by chlorination. Three minutes after injection of hypochlorite in the discharge basin, bromoform reached 60% of its maximum concentration (29.23 µg/l). The maximum reaction yield of bromoform formation is 2.9 %. Three zones were defined according to their proximity to releases. In each zone, given the lack of precision in measurements, the concentration of residual oxidants found did not reach significant levels ≤0.03 mg/L. The bromoform concentration, on the contrary, reached measurable levels in each of the samples. Its distribution differs significantly from one zone to another: -release zone : 1.66±0.40 µg/l -nearby zone: 0.44±0.13µg/l - distant zone : 0.26±0.10µg/l. Our analysis, which indicates a background level of the order of 0.1 µg/l for the entire studied area, raises the question of possible other sources of bromoform, independent of discharge from Penly.

Kim, S.Y. and T.Y. Lee. 1989. The effects of Pollutants effluent from a steam-power plant on coastal bivalves. Contr. Inst. Marine Science of National Fisheries, University of Pusan: 223-242.

A study of the toxic effects on egg development and adult tissue of 3 marine bivalve species was performed using 4 main Pollutants from a steam-power plant. The bioassay consisted of 2 experiments, one which studied egg development of *Crassostrea gigas* and *Mytilus edulis* in various concentrations of Cu ($CuSO_4$), Cl (NaOCl), Fe ($FeCl_2$) and HCl and the other studied histological changes of adult bivalves, *C. gigas, M. edulis*) and *Tapes philippinarum* in various concentrations of the same Pollutants.

Kristiansen, N.K., M. Froeshaug, K.T. Aune and G. Becher. 1994. Identification of halogenated compounds in chlorinated seawater and drinking water produced offshore using n-pentane extraction and open-loop stripping technique. Environmental Science & Technology 28(9): 1669-1673.

The formation of byproducts in chlorinated seawater used for drinking water production on three oil installations was investigated with the use of n-pentane and open-loop stripping extraction. The use of capillary gas chromatography (GC) with electron capture detection (ECD) and mass spectrometry (MS) revealed the presence of a great variety of bromine-substituted aliphatic and aromatic compounds in both chlorinated seawater and tap water. Tribromomethane and dibromoacetonitrile were found in tap water in the range of 19-27 µg/L and 0.9-1.6 µg/L, respectively, and these major byproducts were most efficiently extracted with n-pentane. However, the open-loop stripping technique was better suited for extraction of halogenated compounds present at the low nanograms per liter level, such as the iodinated trihalomethanes. When using n-pentane for extraction of chlorination byproducts, the formation of artifacts such as 3-bromo-2-methyl-2-butanol and other halogenated C_5 compounds was observed. These compounds were presumably formed from the reaction of excessive halogen with traces of olefins in the solvent. While ammonium sulfate only partly prevented the formation of the artifacts, sodium thiosulfate was efficient as a quenching agent and completely destroyed reactive halogen.

Kurelec, B., S. Britvic, M. Rijavec, B. Sieben, N. Bihari, W.E.G. Mueller and R.K. Zahn. 1983. Sea water chlorination: Creation of mutagenic byproducts. Rapp. P.-V. Reun. Ciesm 28(7): 135-136.

Recently it came to light how water chlorination generates carcinogens and mutagens. In addition to the formation of a small number of the mutagenic low molecular weight halogenated methanes (haloforms) there is also a potential to produce high molecular weight mutagenic substances. Some of these have been identified as derivatives from natural organic material dissolved in sea water. Coastal regions differ with regard to the quantity and quality of dissolved organic molecules due to the depth or due to the extent of environmental contamination. Consequently, the antibiofouling chlorination of the rather huge amounts of sea water used in cooling systems results in large amounts of mutagens.

Lamon-Doherty Biossay Work. 1993. in Appendices Vol. III, Sect. III E. In: Environmental Report, Indian Point, No. 3, Consolidated Edison Co. of New York Inc., New York.

No abstract.

"Laurer's Bioassy Work". 1973. in Appendices Vol. III, Sect. IIIC. In: Environmental Report, Indian Point No. 3, Consolidated Edison Co. of New York, Inc., New York, NY.

No abstract.

Laurer, G.J. , W.T. Waller, D.W. Bath, W. Meeks, R. Heffer, T. Ginn, L. Zubarik, P. Bibko and P.C. Storm. 1974. Entrainment studies on Hudson River organisms. Pp. 37-82. In: L.D Jensen (ed). Proceedings of the Second Workshop on Entrainment and

Intake Screening. Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD.
No abstract.

Lassus, P., P. Maggi, C. Le Baut, M. Bardouil, G. Bocquene, L. Le Dean and P. Truquet. 1981. The effects on chorination on the first larval stages of *Palaemon serratus*. Revue des Travaux de l'Institut des Peches Maritimes Nantes 45(1): 85-95.
In order to estimate the effects of chlorine used in cooling systems of electric power plants on zooplankton, some experiments have been realized with the four first larval stages of the prawn (*Palaemon serratus* Pennant). Chlorine injection was performed by constant adding at 16 and 20°C with time exposures of 5, 15 and 25 minutes. If there is no detectable variation in sensitiveness of different stages, toxic effects of oxydants issued from chlorination can be observed (for both the two acclimation temperatures) at 15 minutes exposure with a LD 50 : 3 mg/L of chlorine.

Lebreton, P. 1976. Ecological consequences of atomic power stations on the sea shore. Bulletin d'Ecologie 7(1): 33-59.
Ecological effects of giant nuclear power plants on the coastal environment are reviewed. Physical problems are discussed, e.g., the necessity of ecological mapping. Mechanical problems include the cooling systems and disturbance of marine micro- and macro-organisms. The heated discharges cause thermal pollution. Effects on dissolved chemicals and marine organisms, aquaculture and its limits are discussed. Chemical and radiochemical aspects discussed include synergistic Pollution, chlorination vs. fouling, acute or chronic radioactive effluents and concentration by food chains. Plurilogical categories can be distinguished on the basis of physical water turn-over; to these categories correspond various standards and recommendations for management of nuclear power plants in coastal zones.

Liden, L.H. and D.T. Burton. 1977. Survival of juvenile Atlantic menhaden (*Brevoortia tyrannus*) and spot (*Leiostomus xanthurus*) exposed to bromine chloride and chlorine-treated estuarine waters. Journal Environmental Science Health A12: 375-388.
No abstract.

Liden, L.H., D.T. Burton, S.L. Margrey and L.H Bongers. 1979. Comparative biotoxicity of bromochlorinated and chlorinated power plant condenser cooling waters to selected estuarine organisms. Association Southeastern Biology Bulletin 26: 83.
No abstract.

Liden, L.H., D.T. Burton, L.H. Bongers and A.F. Holland. 1980. Effects of chlorobrominated and chlorinated cooling water on estuarine food-chain organisms. Journal of Water Pollution Control Federation 52: 173-183.

Toxicities of chlorobrominated and chlorinated cooling waters to selected estuarine food chain organisms were investigated during an on-site power plant study. Survivals were similar among juvenile Atlantic menhaden (*Brevoortia tyrannus*) and spot (*Leiostomus xanthurus*) after exposures to BrCl and Cl2 treated condenser effluents. Juvenile American oysters (*Crassostrea virginica*) and brackish water clams (*Rangia cuneata*) had no halogen attributable mortalities after 15 day exposures. Similar survival reductions were recorded for copepods (*Acartia tonsa*) subjected to BrCl or Cl2 residuals (< 0.100 mg/L) for 24 h. eductions in O2 evolution (77-388%) and C-fixation (40-71%) rates and increased respiration rates (56-1276%) of entrained phytoplankton were recorded from both chlorobrominated and chlorinated samples. BrCl and Cl2 residuals appeared to have similar toxicities to estuarine organisms.

Lou, K., E. Xu and J. Su. 1981. Studies on elimination of mussel growths in pipelines by chlorination. Oceanologia et Limnologia Sinica 12(2): 117-124.

No abstract.

Lovell, C.R. 1999. Degradation of haloaromatic compounds by indigenous sediment microflora: biochemistry and molecular ecology. Report for 15 Jan 96-31 Mar 99. Dept. of Biological Sciences, South Carolina Univ., Columbia: 94 pp.

This study examined microbial communities in biofilms lining marine infaunal burrows with particular focus on marine bacteria able to degrade chlorinated aromatic compounds. These biofilms contain a diverse and abundant microbiota, occurring as single cells and in microcolonial formations. The majority of these organisms are potentially active. The burrow biofilm microbiota includes bacteria able to remove halogen atoms from the aromatic ring of haloaromatic compounds. At least some of these bacteria are amenable to isolation and can be cultivated in the laboratory. Reductively dechlorinating bacteria were enriched from burrows produced by both haloaromatic producing and non-producing marine infauna. It is clear from these results that marine dechlorinating bacteria are common in infaunal burrow structures relative to bulk sediments. Two isolates able to debrominate bromophenols were characterized and identified as novel strains of *Propionigenium maris*. Microscopic examination also revealed the potential for interspecific interactions among dehalogenating bacteria and other types of organisms. These interactions may include consortial metabolism of chloroaromatics. The study revealed and characterized an important and previously unrecognized niche for reductively dehalogenating bacteria in marine sediments. Infaunal burrow structures provide a source for new organisms with potential application in bioremediation processes.

Macalady, D.L., J.H. Carpenter and C.A. Moore. 1977. Sunlight-induced bromate formation in chlorinated seawater. Science 195(4284): 1335-1337.

Chlorinated waters are being introduced into estuarine and coastal areas in increasing quantities. In such systems, the chlorine reacts with the natural bromide and ammonia to produce the highly toxic hypobromous acid, hypobromite ion, and haloamines. Sunlight causes up to 50% conversion to bromate ion, which is persistent in natural waters and has an unknown toxicity.

Marcy, B.C. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. Journal Research Board Canada 30: 1195-1203.

No abstract.

Marcy, B.C., A.D. Beck and R.E. Ulanowicz. 1978. Effects and impacts of physical stress on entrained organisms. Pp. 135-188. In: J.R. Schurbel and B.C. Marcy, J. (eds). Power Plant Entrainment: A Biological Assessment.

No abstract.

Margrey, S.L., D.T. Burton and L.B. Richardson. 1976. A preliminary study of chlorine toxicity to Atlantic menhaden (*Brevoortia tyrannus*) and hogchoker (*Trinectes maculatus*). Association Southeastern Biology Bulletin 23: 78.

No abstract.

Margrey, S.L., D.T. Burton and L.W. Hall. 1981. Seasonal temperature and power plant chlorination effects on estuarine invertebrates. Archives of Environmental Contamination and Toxicology 10(6): 691-703.

The influence of seasonal temperatures (15-22°C) on chlorine (0.00, 0.15 and 0.30 mg/L total residual chlorine), ΔT (2,6 and 10°C), and exposure duration (0.08, 2.0 and 4.0 hr) interaction studies simulating power plant entrainment and effluent discharge conditions was evaluated for opossum shrimp, *Neomysis americana* and amphipods, *Gammarus* sp. Seasonal temperature was an important factor affecting the toxicity of the three treatment variables with both of these organisms. Mortality responses were greater at the higher acclimation temperature

Marine Research Inc., Boston Edison Co., Nuclear Engineering Department, 800 Boylston St., Boston, MA 02199, USA. 1976. Entrainment investigations and Cape Cod Bay ichthyoplankton study, September - December, 1975. Twelve-month summary for 1975. Marine ecology studies related to operation of Pilgrim Station. Semi-annual Report No.7.

Phytoplankton and zooplankton entrained at Pilgrim appear to be unharmed by entrainment, except during chlorination when damage is severe. Except during the months of June and July, when labrid eggs were particularly abundant near shore, ichthyoplankton densities in the Pilgrim discharge were generally lower than in the surrounding waters. It is estimated that during the summer months, 31% of the fish eggs entrained at Pilgrim fail to survive. Labrid eggs and the larvae of some spp are found in significantly greater abundance at the stations near Pilgrim than in the Bay as a whole, whereas for other spp, the converse is true. Analyses of the distribution of certain spp of bivalve larvae and finfish eggs and larvae in Plymouth Bay tend to indicate that the Pilgrim station draws its cooling water primarily from an inshore water mass that fills Plymouth Bay and extends southeastward as a relatively narrow band along the shore. Results of the lobster larvae survey in Cape Cod Bay suggest the Cape Cod Canal was a primary source of larvae for the Bay during 1975.

Markowski, S. 1959. The cooling water of power stations: A new factor in the environment of marine and freshwater invertebrates. The Journal of Animal Ecology 28(2): 243-258.

1. A number of power stations were surveyed to see whether the cooling water system had any effect on the aquatic invertebrates found in fresh and sea water. 2. The samples of zooplankton were collected in the intake and in the outfall waters for quantitative and qualitative investigations. 3. Some thirty-five freshwater and sixty-two marine species were identified. 4. No detrimental effect on the organisms found was observed. They were alive after being circulated through the condensers. 5. No difference in fauna composition between the intake and the outfall was found from the qualitative and quantitative points of view. 6. Freshwater forms are able to live and reproduce in the cooling ponds of the power station. 7. The chemical and physical features of the cooling water were given.

Marumo, K., F. Sato and Y. Ishikawa. 1992. Experimental study on acute effects of the combined exposure to temperature increase and chlorination upon the marine copepod *Acartia omorii*. Marine Biology. 114(2): 235-240.

The acute effects of combined exposure to temperature increase and chlorination on a neritic marine copepod, *Acartia omorii* (collected offshore of Onjuku, Japan in 1982), were investigated in the laboratory. Continuous flow exposure and batch exposure modes were compared. Based on the results of continuous flow experiments, the 24-h median lethal concentration (24-h LC_{50}, in mg/L) of total residual chlorine was estimated using the multiple regression equation below, with a multiple correlation coefficient of 0.955: 24-h $LC_{50} = 2.988 - 0.034\ dT - 1.611 \log_{10} t$ where dT is temperature rise (°C) and t is exposure duration (minutes). In batch experiments, the predictive power of the multiple regression equation was reduced, probably due to variations in chlorine concentration during exposure duration.

Masilamoni, G.J., K. Nandakumar, K. Satapathy and Azariah, J. 2002. Lethal and sublethal effects of chlorination on green mussel *Perna viridis* in the context of biofouling control in a power plant cooling water system. Marine Environmental Research 53(1): 65-76

Continuous chlorination is a widely followed cooling water treatment practice used in the power industry to combat biofouling. The green mussel *Perna viridis* is one of the dominant fouling organisms (> 70%) in the Madras Atomic Power Station.

Mattrice, J.S. 1977. Power-plant discharges: toward more reasonable effluent limits on chlorine. Resource Relations Nuclear Safety Oak Ridge National Lab., TN 18(6): 802-819.

A method is presented for restricting chlorine in power-plant effluents to environmentally safe levels. Development of this method was stimulated by the controversy between electric utilities and regulatory agencies over the justification of the present universally applied limits. The scientific literature conclusively demonstrates the effects of physical, chemical, and biotic factors on chlorine toxicity. The method proposed includes these factors, to the extent currently possible, to set limits based on site-specific aquatic conditions and plant design and operation specifications. In these effluent limits, the organisms considered are those which are entrained into the plume or which maintain themselves within the plume during chlorination. In each instance the time course of exposure concentration is divided into small time intervals. Weighted mean concentrations for successively larger time intervals following initial exposure are then calculated. Exposures resulting from releases at various levels are compared either graphically or mathematically with acute and chronic mortality thresholds to find the highest discharge concentration that does not cause mortality. The thresholds are derived from existing toxicity data and are different for marine and freshwater organisms. This method is based on the latest literature available and can incorporate further data concerning chemistry, toxicity, and behavior as they become available. The method also is amenable to coupling with models of chemical dispersion and population dynamics to permit more complete analysis. This approach serves to permit use of chlorine for biofouling control at power plants, while ensuring that this use will not be inimical to the environment.

Mattrice, J.S. and H.E. Zittel. 1976. Site-specific evaluation of power plant chlorination. Journal of Water Pollution Control Federation 48(10): 55-65.

The literature on chlorine toxicity to aquatic organisms is critically reviewed regarding methodology. Extant toxicity data for marine and freshwater organisms are summarized using log concentration versus log time plots of median tolerance (50%) levels. Acute and chronic toxicity thresholds are approximated by enclosing these data points and then shifting the resultant lines. The chronic toxicity threshold for fresh water is 0.0015 mg/L, while that for salt water is 0.02 mg/L. A site-specific procedure for evaluating chlorination schemes at a power plant is proposed based on comparison of dose-times expected in its discharge plume with the above toxicity thresholds. Dose-times higher than the threshold are considered to yield mortality while those below it are not toxic. An analysis of a hypothetical marine-based power plant is presented.

McLean, R.I. 1972. Chlorine tolerance of the colonial hydroid *Bimeria franciscana*. Chesapeake Science 13: 229-230.

The euryhaline colonial hydroid *Bimeria franciscana* was experimentally exposed to various concentrations of chlorine to determine the effect of power plant chlorination on growth. Colonies attached to suspended nylon lines were exposed to 0.0, 1.0, 1.5, 2.5, 3.5, 4.5 ppm total chlorine for 1 and 3 hr, and returned to their natural habitat. Growth

occurred in all colonies and was slightly inhibited in colonies exposed to the higher chlorine concentrations.

McLean, R.I. 1973. Chlorine and temperature stress on estuarine invertebrates. Water Pollution Control Federation 45(5): 837-841.

Five species of estuarine invertebrates subject to entrainment in the cooling water system of a steam electric station were exposed experimentally to chlorine and temperature stresses simulating plant operations. Estuarine water was injected with chlorine gas to achieve a final concentration of 2.5 mg/L total chlorine residual. This concentration effected as high as 80% population mortality in the barnacle nauplii Balanus species and 90% in the copepod *Acartia tonsa* during a 5-minute exposure. Temperature elevations of 10°F (5.5°C) and 20°F (11°C) for 3 hours had no significant effect on population mortality. 2 amphipods, *Gammarus* species and *Melita nitida*, and one species of shrimp, *Palaemonetes pugio*, exhibited greater tolerance to the same stress conditions.

Mehrtens, G. and F. Laturnus. 1999. Mixed function oxidase dependent biotransformation of polychlorinated biphenyls by different species of fish from the North Sea. Chemosphere 38(13): 2995-3002.

Mixed function oxidase (MFO) dependent biotransformation of polychlorinated biphenyls (PCBs) was measured in three different fish species from the North Sea. Liver microsomes of plaice (*Pleuronectes platessa*), dab (*Limanda limanda*) and cod (*Gadus morhua*) were isolated and incubated with different PCB congeners. Metabolites of PCBs were identified as monohydroxylated PCBs. Hydroxylation took place in meta- or para-position of the PCB molecules, preferential in para-position. Metabolization and metabolic rates depended on the substitution pattern of PCBs and the degree of chlorination. Biotransformations were also species dependent. The flatfish dab and plaice exhibited higher metabolic rates than cod.

Meldrim, J.W. and J.A. Flava, Jr. 1977. Behavioral avoidance responses of estuarine fishes to chlorine. Chesapeake Science 18: 154-157.

No abstract.

Meldrim, J.W., J.J. Gift and B.R. Petrovsky. 1974. The effect of temperature and chemical Pollutants on the behavior of several estuarine organisms. Bulletin No. 11, Ichthyological Associates, Inc., Ithaca, NY.

No abstract. Link to full-text: http://estuaries.olemiss.edu/cgi-bin/est/public_access_search4.pl

Middaugh, D.P. and W.P. Davis. 1975. Impact of chlorination processes on marine ecosystems. Water quality criteria research of the U.S. Environmental Protection

Agency. Proceedings of an EPA-sponsored symposium on marine, estuarine and fresh-water quality - presented at the 26th annual meeting of AIBS, August 1975. No. 600/3-76-079, [Ecol. Research Ser.USEPA]. Jul 1976. No pagination.

The use of chlorine as a disinfectant and antifouling agent is reviewed. Chemical reactions of chlorine in aquatic environments are discussed, with particular emphasis on the formation of halogenated organic constituents in freshwater and marine systems. Studies of the effect of chlorinated sewage effluents and cooling water from generating stations on marine organisms and ecosystems are summarized.

Middaugh, D.P., J.A. Couch and A.M. Crane. 1977a. Responses of early life history stages of the striped bass, *Morone saxatilis* to chlorination. Chesapeake Science 18: 141-153.

The toxicity of total residual chlorination (TRC) to early life stages of the striped bass, *Morone saxatilis*, was determined using percent embryo hatchability, incipient LC_{50} bioassays, histopathology, and avoidance responses. Beginning 8 to 9 hours after fertilization, developing embryos were exposed continuously to TRC in flowing water at 1.0-3.0 ppt salinity and 18 +/- 1 ^oC. Fifty-six% of the control group (no TRC exposure) hatched. None of the embryos exposed to a measured TRC concentration of 0.21 mg/L hatched. Only 3.5% of the embryos exposed to 0.07 mg/L TRC and 23% of those exposed to 0.01 mg/L TRC hatched. Incipient LC_{50} bioassays were used to determine the sensitivity of 2-, 12- and 30-day-old striped bass to concentrations of TRC in flowing water (1.0-3.0 ppt salinity at 18±1^{o}C). The estimated incipient LC_{50} was 0.04 mg/L TRC for 2-day-old prolarvae, 0.07 mg/L for 12-day-old larvae and 0.04 mg/L for 30-day-old juveniles. Histological examination of 30-day-old juveniles which survived exposure in the incipient LC_{50} bioassay indicated gill and pseudobranch damage for fish exposed to 0.21 to 2.36 mg/L TRC. Statistical analysis of avoidance tests conducted at 1.0-3.0 ppt salinity and 18 ± 1 ^{o}C with 24-day-old larvae showed significant (X^2, $p < 0.05$) and reproducible avoidance responses to measured TRC concentrations of 0.79-0.82 mg/L and 0.29-0.32 mg/L. No avoidance was indicated at TRC concentrations of 0.16-0.18 mg/L.

Middaugh, D.P., J.A. Couch and A.M. Crane. 1977b. Toxicity of chlorine to juvenile spot, *Leiostomus xanthurus.* Water Research 11: 1089-1096.

The sensitivity of juvenile spot, *Leiostomus xanthurus*, to total residual chlorine (TRC) in flowing sea-water was investigated. Incipient LC_{50} bioassays, histopathology, avoidance tests and the combined effect of thermal stress and TRC were used to assess sensitivity. Estimated incipient LC_{50} values were 0.12 mg/L TRC at 10°C and 0.06 mg/L TRC at 15°C. Histological examination of spot used in the incipient LC_{50} bioassay at 15°C and sacrificed while alive indicated pseudobranch and gill damage occurred in individuals exposed to a measured TRC concentration of 1.57 mg/L. Spot exposed to lower concentrations of TRC, 0.02-0.06 mg/L at 15°C and sacrificed alive showed no consistent tissue damage. Spot demonstrated temperature dependent avoidance responses to TRC. At 10°C, a concentration of 0.18 mg/L was required for significant (X^2; $P <$ 0.05) avoidance; at 15 and 20°C, spot showed significant avoidance of TRC concentrations as low as 0.05 mg/L. Simultaneous exposure of spot to thermal stress (5,

10 or 13°C above the acclimation temperature of 15°C) at measured TRC concentrations of 0.05 0.07 and 0.34–0.52 mg/L demonstrated a significant, (Z^2) with Yates correction, $P < 0.05$) increase in sensitivity to TRC with increased temperature and exposure times for some of the groups tested.

Middaugh, D.P., J.M. Dean, R.G. Domey and G. Floyd. 1978. Effect of thermal stress and total residual chlorination on early life stages of the mimmichog, *Fundulus heteroclitus*. Marine Biology 46: 1-8.

Effects of simultaneous short-term (7.5-60 minutes) thermal stress (24-34°C) and total residual chlorination (0.05-1.0 mg/L) on specific development stages of the mummichog *F. heteroclitus*, were investigated. For the embryonic stages, total number of successfully hatched larvae was used as the criterion to measure effect. For larval stages, survival 24 h exposure was used. In embryonic stages, temperature was the most important main variable. Only 1 embryonic stage (gastrula) was confounded by 2nd-order interactions (temperature x duration of exposure x total residual chlorination). Both 0-day and 7 day old larval stages showed significant higher-order interactions for all combinations of test parameters, suggesting the presence of synergistic effects of the 3 main experimental variables.

Morgan, R.P. and R.G. Stross. 1969. Destruction of phytoplankton in the cooling water supply of a steam electric station. Chesapeake Science 10: 165-171.

Rates of photosynthesis were used to evaluate the response of phytoplankton when passed through the cooling system of a power generating facility. Photosynthesis was measured as the uptake of carbon. A factorial design permitted evaluation of heat input, total effect of passage, and degree of recovery. Six experiments measured response at a fixed time of day and at various times in a daily cycle. An increase in temperature of approximately 8.0 ^{o}C stimulated photosynthesis when natural water temperatures were 16 ^{o}C or cooler and inhibited photosynthesis when natural water temperatures were 20 ^{o}C or warmer. Passage through the cooling system resulted in further inhibition when the water was warm and nullified thermal stimulation when the water was cool. No recovery was observed within a four hour period following passage. Photosynthesis in cooled effluent water was either unaffected or actually suppressed. The existence of daily synchrony in the algae was shown by a daily maximum of thermal stimulation at 0900. The rhythm is considered inherent and only amplified by warming.

Morgan, R.P. and R.D. Prince. 1977. Chlorine toxicity to eggs and larvae of five Chesapeake Bay fishes. Transnational American. Fish Society 107: 636-641.

Eggs and larvae of white perch (*Morone americana*), striped bass (*Morone saxatilis*) and blueback herring (*Alosa aestivalis*) and eggs of Atlantic silversides (*Menidia menidia*) and tidewater silversides (*M. beryllina*) were exposed to various residual chlorine levels for preestablished periods. Almost all LC_{50} values fell between 0.20-0.40 ppm of total residual chlorine for eggs, and between 0.20-0.32 ppm for larvae.

Age-related effects in sensitivity to chlorine were observed. Abnormal larvae issued from blueback herring eggs exposed to low chlorine concentrations.

Morgan, R.P. and R.D. Prince. 1978. Chlorine effects on larval development of striped bass (*Morone saxatilis)*, white perch (*M. americana)* and blueback herring (*Alosa aestivalis)*. Transnational American Fish. Society 107: 636-641.

Eggs of striped bass (*M. saxatilis*), white perch (*M. americana*) and blueback herring (*A. aestivalis*) were exposed to a series of total residual Cl (TRC, a biocide) concentrations until hatch occurred. Larval development of the 3 species was inhibited by increasing TRC concentrations. Length of larval fish at hatch decreased with increasing TRC concentrations and the production of abnormal blueback herring larvae increased with increasing TRC concentrations.

Morgan, R.R., D.A. Flemer, L.A. Noe, J.V. Rasin and R.A. Murtagh. 1974. Biochemical studies of entrained phytoplankton at the Morgantown Maryland Power Plant. Pp. 165-168. In: L.D Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD.

No abstract.

Morris, R.J., F. Culkin, A.P.M. Lockwood and A.C. Jensen. 1983. Effect of chlorination on the gill lipids of the mussel *Mytilus edulis* (L.). Chemistry and Ecology 1(3): 173-189.

Experiments are described which involve the chlorination of standard solutions of lipids and populations of the mussel, *Mytilus edulis* (L). The object was to test the hypothesis that chlorine will bind to unsaturated lipids. Evidence is presented that chlorine and aqueous chlorinated species rapidly and readily form addition compounds with unsaturated lipids in vivo as well as in vitro. The relevance of these findings to possible environmental effects of chlorination is discussed.

Mount, D.R. and W. Quast. 1993. Assessing toxicity of varying major ion concentrations to marine organisms. 14th Annual Meeting (SETAC) - Ecological Risk Assessment: Lessons Learned? -- Pensacola Conference. No pagination.

Recent regulatory developments have required that produced waters discharged in the Gulf of Mexico be monitored for toxicity to marine organisms. While produced water may contain a variety of indigenous and introduced chemicals, virtually all have moderate to high concentrations of major ions (e.g., sodium, chloride). Although seawater is also rich in these ions, excessive (or insufficient) salinity can cause toxicity to marine organisms. Perhaps more importantly, toxicity to marine organisms can be caused by deviations from normal ion ratios (relative to seawater) even if the total salinity is within organism tolerances. To provide a better understanding of marine organism responses to variations in major ion concentrations, we conducted a series of laboratory experiments to quantify the responses of mysid shrimp (*Mysidopsis bahia*) and

sheepshead minnows (*Cyprinodon variegates*) to modifications of normal seawater chemistry. Acute testing included both increasing and decreasing the concentrations of individual ions relative to seawater, as well as altering total salinity. Results show these organisms can be adversely affected by this altered chemistry and their sensitivity is dependent upon the individual ions that are manipulated. Results from these studies are being incorporated into an overall strategy for evaluating the influence of major ion chemistry on produced water toxicity tests. (DBO)

Muchmore, D. and D. Epel. 1973. The effects of chlorination of wastewater on fertilization in some marine invertebrates. Marine Biology 19(2): 93-95.

Unchlorinated domestic sewage was a relatively weak inhibitor of external fertilization in 3 marine invertebrates (*Strongylocentrotus purpuratus, Urechis caupo, Phragmatopoma californica*). Chlorinated sewage was a potent spremicide, active in inhibiting fertilization in concentrations of available chlorine as low as 0.05 ppm. Sodium hypochlorite in seawater duplicated the effect, and excess sodium thiosulfate terminated it. The possibility of chlorine disinfection affecting reproductive success in the vicinity of outfalls is discussed.

Mulford, R.A. 1974. Morgantown entrainment Part IV, phytoplankton taxonomic studies. Pp. 169-175. In: L.D Jensen (ed). Proceedings of the Second Workshop on Entrainment and Intake Screening. The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD.

No abstract.

Nalewajko, C. and T.G. Dunstall. 1994. Miscellaneous Pollutants: Thermal effluents, halogens, organochlorines, radionuclides. Advances in Limnology Report: 7 pp.

Phytoplankton may become entrained in water intake of power plants and pass through the cooling system where they are exposed to a sudden increase in temperature. Photosynthetic rates are used to assess the impact of entrainment on phytoplankton. From these studies it became apparent that in the absence of a chlorination treatment, at low ambient water temperature, photosynthesis was either unaffected or stimulated after passage of the algae through the cooling system. The photosynthetic response encountered in these various entrainment studies depends for the most part on total temperature attained during station passage.

Nicholson, B.C., G.R. Shaw, J. Morrall, P.J. Senogles, T.A. Woods, J. Papageorgiou, C. Kapralos, W. Wickramasinghe, B.C. Davis, G.K. Eaglesham and M.R. Moore. 2003. Chlorination for degrading saxitoxins (paralytic shellfish poisons) in water. Environmental Technology 24(11): 1341-1348.

Chlorination was investigated as a treatment option for degrading and thus removing saxitoxins (paralytic shellfish poisons, PSPs) produced by cyanobacteria (blue-green algae) from water. It was found to be effective with the order of ease of degradation of the saxitoxins being GTX5 (B1) similar to dcSTX > STX > GTX3 similar to C2 > C1 > GTX2. However the effectiveness of chlorine was pH dependent. Degradation as a function of pH was not linear with the degree of degradation increasing rapidly at around pH 7.5. At pH 9 > 90% removal was possible provided a residual of 0.5 mg/L free chlorine was present after 30 minutes contact time. The more effective degradation at higher pH was unexpected as chlorine is known to be a weaker oxidant under these conditions. The more effective degradation, then, must be due to the toxins, which are ionisable molecules, being present in a form at higher pH which is more susceptible to oxidation. The feasibility of using chlorine to remove saxitoxins during water treatment will therefore depend strongly on the pH of the water being chlorinated. Degradation may be improved by pH adjustment but may not be a practical solution. Although saxitoxins were degraded in that the parent compounds were not detected by chemical analysis, there is no indication as to the nature of the degradation products. However, acute toxicity as determined by the mouse bioassay was eliminated.

Oceanographique, J.D.R. 1998. Coastal zone monitoring and medium to long term forecasting. Journal Research Oceanography 23 (1): 21-35.

Several methodologies and tools both used by Japan and France for coastal monitoring and forecasting are presented. Chemical treatment (sea water chlorination), measurements of time-weighted average concentration of benzo(a)pyrene in marine environment, telluric inputs, macrobentic communities responses to organic load, annelids polychaetes responses to organic Pollution, and quantitative measurement of coral biomass are given as experiments.

Opresko, D. 1982. Review of open literature on effects of chlorine on aquatic organisms. T. Oak Ridge National Lab., Government Reports Announcements. Issue 6: 320 pp.

The pre-1980 open literature on the chemistry and Biological effects of chlorine in marine, freshwater, and estuarine systems is reviewed with special emphasis placed on the potential impacts of power plant chlorination practices. Information is provided on aqueous chlorine chemistry including the types and relative concentrations of residual oxidants formed under varying environmental conditions; the stability, persistence, and reactivity of these oxidants; and their potential for forming halogenated organic compounds. Analytical methods for differentiating and measuring chlorine-produced residual oxidants are discussed in a separate section. Information on Biological effects, derived mainly from the results of laboratory bioassays, consists primarily of acute toxicity data, but also included are discussions of Biological and environmental factors affecting species' tolerance levels; sublethal effects on reproduction, growth, behavior, and physiological processes such as respiration and osmoreg.

Opresko, D. 1983. Effects of chlorine on aquatic organisms: A review of the literature with special reference to cooling water chlorination. T. Oak Ridge National Lab., Government Reports Announcements. Issue 22: 318 pp.

The pre-1980 open literature on the chemistry and Biological effects of chlorine in marine, freshwater, and estuarine systems is reviewed with special emphasis placed on the potential impacts of power plant chlorination practices. Information is provided on aqueous chlorine chemistry including the types and relative concentrations of residual oxidants formed under varying environmental conditions; the stability, persistence, and reactivity of these oxidants; and their potential for forming halogenated organic compounds. Analytical methods for differentiating and measuring chlorine-produced residual oxidants are discussed in a separate section. Information on Biological effects, derived mainly from the results of laboratory bioassays, consists primarily of acute toxicity data, but also included are discussions of Biological and environmental factors affecting species' tolerance levels; sublethal effects on reproduction, growth, behavior, and physiological processes such as respiration and osmoreg.

Pacheco Ruiz, I., A. Galvez-Telles, J.A. Zertuche-Gonzalez and J.L. Pech. 1997. Effect of using commercial chlorine ($HClO_3Na$) on the growth of epiphyte algae and their host *Gigartina pectinata* Daw. (Gigartinales, Rhodophyta). Ciencias Marinas 23(3): 395-401.

Different concentrations of commercial chlorine were used to control the growth of epiphytes on cultured red algae *Gigartina pectinata*. Results showed that the better concentration was 100 microliters per liter which was lethal for all the epiphytes but didn't affect the growth of *G. pectinata.*

Peck, B.B. and R.S. Warren. 1978. Nitrate reduction activity and primary productivity of phytoplankton entrained through a nuclear power station on northeastern Long Island Sound. Pp. 392-409. In: J.H. Thorp and J.W. Gibbons (eds). Energy and Environmental Stress in Aquatic Systems. DOE Symposium Series 48 CONF-771114.

No abstract.

Peres, G. 1988. The use of chemicals in the marine environment. Oceanis. Serie de documents oceanographiques. Devenir des Pollutants Chimiques en Milieu Marin, Brest (France), 26-27 Jan. Conference Proceedings. Vol.14(6): No pagination.

The protection of industrial refrigeration circuits has been considered first. Chlorination has long been employed and the efficiency of this method and its possible action on the marine environment is assessed. Secondly we are concerned with antifouling paint used to protect hulls and marine culture equipment. A survey of the principal biocides has been made with special reference to the organostannic compounds. Past experience and knowledge of effects on the environment and fish farms point to the need to regulate the use of these chemicals.

Perissinotto, R. and T. Wooldridge. 1989. Short-term thermal effects of a power-generating plant on zooplankton in the Swartkops Estuary, South Africa. Pubblicazioni della Stazione zoologica di Napoli I: Marine Ecology 10(3): 205-219.

The short-term effect of elevated water temperatures (Δt = 5-10°C after passing through the cooling circuit of an electricity generating plant) on plankton in a warm temperate estuary, South Africa, was investigated. Phytoplankton entrained on the flood tide was more severely affected than that entrained on the ebb, but chlorination of cooling water was probably a major factor affecting phytoplankton assemblages. Abundance of zooplankton of marine origin was significantly reduced after passing through the cooling circuit. The effect of thermal stress on the euryhaline zooplankton was not clear.

Pinkney, A. 1992. Summary of recent information on biofouling control at power plants. - Final report. I. Versar, Columbia, MD. Annapolis, Maryland Power Plant Research Program: 26 pp.

Control of fouling organisms at power plants requires large investments by utilities. This report provides an overview of power plant biofouling and control techniques, a discussion of research and technologies investigated nationally, and a description of studies conducted at Maryland power plants. The major biofouling control techniques currently under investigation are: (1) using sodium bromide and bromine chloride in place of and in addition to chlorine; (2) conducting chlorine minimization studies and targeted chlorination trials to use chlorine more effectively; (3) using mechanical cleaning as an alternative method of controlling fouling; and (4) applying non-toxic coatings to intake structure An important issue is the increased use of bromine and mollucides at power plants and the establishment of discharge limits. Chlorine minimization studies are in progress or have been completed recently at several Maryland power plants but results are not yet available. Targeted chlorination is a promising technique for reducing chlorine usage. At some plants, mechanical cleaning has controlled condenser tube fouling and is used in place of biocides. Several trials have demonstrated the effectiveness of non-toxic coatings for reducing fouling on intake structures; however, cost savings are not yet apparent.

Public Service Electric and Gas Company. 1978. Temperature and chemical avoidance studies Sect. 4.2.3. in Annual Environmental Operating Report , Salem Nuclear Generating Station- Unit 1, 1977 Report. Newark, NJ.

No abstract.

Rainville, R.P., B.J. Copeland and W.T. McKean. 1975. Toxicity of kraft mill wastes to an estuarine phytoplankter. Journal Water Pollution Control Federation 47(3): 487-503.

A study was conducted to evaluate the toxicity of kraft mill wastes to *Coccochloris elebans*. Through a series of bioassays, the effect of these wastes on the growth potential of this organism was determined. Untreated and primary treated effluents were toxic to *C. elebans* in concs as low as 2.5%. At mills using aeration or long term stabilization as secondary treatment, no appreciable final toxicity was found. Brown water was the most important stream in determining the toxicity of the pulp mill wastewater and was toxic in all concs > 14.4%. The most toxic streams within the bleach plant originate from the chlorination, chlorine dioxide, and first caustic extraction stages.

Rajagopal, S. 2001. Can intermittent chlorination really control mussel fouling in industrial cooling water systems? 11th International Conference on Aquatic Invasive Species, Alexandria, VA (USA), 1-4 Oct 2001. (World Meeting Number 000 5699).

Availability: 11th International Conference on Aquatic Invasive Species, 1027 Pembroke Street East, Suite 200, Pembroke, ON K8A 3M4, Canada; phone: 613-732-7068; fax: 613-732-3386; URL: www.aquatic-invasive-species-conference.org

No abstract.

Rajagopal, S., K.V.K. Nair, G. Van Der Velde and H.A. Jenner. 1997a. Response of mussel *Brachidontes striatulus* to chlorination: an experimental study. Aquatic Toxicology 39(2): 135-149.

Though the brackish-water mussel, *Brachidontes striatulus* (Hanley) (syn. *Modiolus striatulus*) is an important fouling animal in power station cooling circuits, there are no published studies on the tolerance of this species to chlorination. Mortality pattern as well as physiological behavior (byssus thread production, foot activity index and filtration rate) of three different size groups (7, 18 and 25mm shell length) of *B. striatulus*, were studied at different chlorine concentrations (0-5 mg/L). At 1 mg/L chlorine residual, 7mm size group mussels showed 100% mortality in 468 h (20 days) and 25mm size group mussels in 570 h (24 days). At relatively high levels of chlorine residuals (5 mg/L), 100% mortality in 7 and 25mm size groups took 102 and 156h, respectively. The exposure time to chlorine required for 100% mortality of *B. striatulus* is much lower than that reported for some other common fouling mussels. Chlorine concentration significantly affected the mean time of death for all size groups of mussels. All size groups showed progressive reduction in physiological activities such as filtration rate, foot activity index and byssus thread production when chlorine residuals were increased from 0 to 1.5 mg/L. Reduction in physiological activities of mussels was strongly correlated with the concentration of chlorine.

Rajagopal, S., G. Van Der Velde and H.A. Jenner. 1997b. Shell valve movement response of dark false mussel, *Mytilopsis leucophaeta*, to chlorination. Water Research 31(12): 3187-3190.

Shell valve movements of fouling mussel, *Mytilopsis leucophaeta*, have been studied in the presence of chlorine, using a mussel monitor. Data showed increasing shell valve closure with increasing chlorine concentration. Shell opening rates of *M. leucophaeta* at control experiments (0 mg/L residual chlorine) were about 10 times more than those at 1 mg/L residual chlorine. Continuous dosing of 0.75 mg/L residual chlorine is required before shell movements are critically affected. Since current environmental stipulations do not permit this, a level of 0.5 mg/L has to be used continuously during settlement periods of *M. leucophaeta* for their control. The results also indicate that *M. leucophaeta* is more tolerant to chlorine than other mussel species.

Rajagopal, S., G. Van Der Velde and H.A. Jenner. 2002a. Does status of attachment influence survival time of zebra mussel, *Dreissena polymorpha*, exposed to chlorination? Environmental Toxicology and Chemistry 21(2): 342-346.

Mussels colonize cooling water circuits of power stations by attaching themselves to the pipe or conduit walls using byssus threads. Once manually detached, they quickly try to reattach by producing new byssus threads. In many published reports on antifouling bioassays, the test specimens are exposed to the biocide in an unattached state. These mussels, while trying to reattach, are likely to expose themselves more frequently to the toxic compound when compared to firmly attached mussels. The results of the assay, therefore, could vary, depending on the status of the mussels used. In this paper, we test the hypothesis that the status of attachment could influence the toxicity response of mussels and show that byssally attached zebra mussel, *Dreissena polymorpha* (Pallas), is more resistant to chlorine than unattached ones. An average increase of 27% in the survival time was observed for attached mussels over unattached ones in the chlorine concentration range of 0.25 to 3 mg/L. It is conclusively shown that the increase in sensitivity of the unattached mussels was related to an increase in the byssal activity, quantified presently as the byssogenesis index. The results indicate that future laboratory toxicity experiments involving mussels should be carried out using byssally attached ones.

Rajagopal, S., G. Van Der Velde and H.A. Jenner. 2002b. Effects of low-level chlorination on zebra mussel, *Dreissena polymorpha*. Water Research 36(12): 3029-3034.

Mortality pattern of different size groups (5-20 mm shell lengths) of the zebra mussel *Dreissena polymorpha* (Pallas), was studied in the laboratory under different chlorine concentrations (0.25-3 mg/L). Results showed that exposure time for 100% mortality of mussels significantly decreased with increasing chlorine concentration. For example, mussels in the 10 mm size group exposed to 0.25 mg/L chlorine residual took 1080 h to reach 100% mortality whereas those exposed to 3 mg/L chlorine took 252 h. All size groups (between 5 and 20 mm shell length) took identical exposure time to reach 100% mortality at given chlorine concentration (between 1 and 3 mg/L). The effect of acclimation temperature on *D. polymorpha* mortality in the presence of chlorine was significant. For example, 1026 h is required to reach 95% mortality using 0.5 mg/L residual chlorine at 10°C, compared to 456 h at 0.50 mg/L chlorine and 25°C. Resistance of *D. polymorpha* to chlorine appeared to be lower than that for other mussel species in The Netherlands viz., *Mytilus edulis* L. and *Mytilopsis leucophaeata* (Conrad). The present study also suggests that 100% mortality data for European populations of *D. polymorpha* at different chlorine concentrations are similar to those for the North American populations.

Rajagopal, S., G. Van Der Velde, M. Van Der Gaag, H.A. Jenner. 2002c. Laboratory evaluation of the toxicity of chlorine to the fouling hydroid *Cordylophora caspia*. Biofouling. 18(1): 57-64.

The brackish water hydroid, *Cordylophora caspia* (Pallas) (syn. *Cordylophora lacustris* Allman) is an important fouling animal in industrial cooling water systems. However, there are no published studies regarding the response of this species to chlorination, which is a widely used antifouling method. The effects of different chlorine concentrations (0.1-1 mg/L total residual chlorine) on growth rate (k) of *C. caspia* were studied in the laboratory. The results show that chlorine is effective at relatively low concentrations (above 0.1 mg/L residual chlorine). The growth rate of *C. caspia* at different chlorine concentrations was dose-dependent. An average decrease of 23% in the growth rate was observed at 0.1 mg/L residual chlorine when compared to control experiments, over a period of 7 d. No growth was recorded at 1 mg/L residual chlorine, indicating threshold levels of residual chlorine on *C. caspia*. The size (length and width) of hydranths decreased significantly as the chlorine concentration increased. Complete hydranth degeneration in 3 d was observed at 1 mg/L residual chlorine. The results also showed that temperatures >30°C (but not lower temperatures) hastened mortality due to chlorine. The combined use of chlorination (0.2 mg/L residual chlorine) and heat (30°C) decreased the growth rate of *C. caspia* by more than 59% when compared to 0.2 mg/L at 20°C.

Rajagopal, S., M. Van Der Gaag, G. Van Der Velde and H.A. Jenner. 2002d. Control of brackish water fouling mussel, *Mytilopsis leucophaeata* (Conrad), with sodium hypochlorite. Archives of Environmental Contamination and Toxicology 43(3): 296-300.

Though the Conrad's false mussel, *Mytilopsis leucophaeata*, is an important fouling animal in industrial cooling water systems, there are no published reports on the tolerance of this species to chlorination. A series of experiments was conducted to determine the effects of mussel size (2-20 mm shell length), season (breeding versus nonbreeding), nutritional status (fed versus starved) and acclimation temperature (5-30°C) on the mortality pattern of *M. leucophaeata* under continuous chlorination (0.25-5 mg/L). The effect of mussel size on *M. leucophaeata* mortality in the presence of chlorine was significant, with 10 mm size group mussels showing greater resistance. At 0.25 mg/L residual chlorine, 2 mm size group mussels took 89 days to reach 100% mortality, whereas 10 mm size group mussels took 109 days. *M. leucophaeata* collected during nonbreeding season (December-April) was more tolerant to chlorine than those collected during breeding season (June-October). Nutritional status of the mussel had no significant influence on the chlorine tolerance of the mussel: fed and starved mussels succumbed to chlorine at equal rates. The effect of acclimation temperature on *M. leucophaeata* mortality in the presence of chlorine was significant. At 0.5 mg/L residual chlorine, mussels acclimated at 5°C required 99 days to reach 95% mortality, whereas mussels acclimated at 30°C required 47 days. A comparison of present data with previous reports suggests that resistance of *M. leucophaeata* to chlorination is higher than other mussel species causing fouling problems in The Netherlands (*Mytilus edulis* and *Dreissena polymorpha*).

Rajagopal, S., G. Van Der Velde, M. Van Der Gaag and H.A. Jenner. 2003a. How effective is intermittent chlorination to control adult mussel fouling in cooling water systems? Water Research 37(2): 329-338.

Mussel control in cooling water systems is generally achieved by means of chlorination. Chlorine is applied continuously or intermittently, depending on cost and discharge criteria. In this paper, we examined whether mussels will be able to survive intermittent chlorination because of their ability to close their valves during periods of chlorination. Experiments were carried out using three common species of mussels: a freshwater mussel, *Dreissena polymorpha*, a brackish water mussel, *Mytilopsis leucophaeata* and a marine mussel, *Mytilus edulis*. The mussels were subjected to continuous or intermittent (4 h chlorination followed by 4 h no chlorination) chlorination at concentrations varying from 1 to 3 mg/L and their responses (lethal and sublethal) were compared to those of control mussels. In addition, shell valve activity of mussels was monitored using a Mussel-monitor(R). Data clearly indicate that mussels shut their valves as soon as chlorine is detected in the environment and open only after chlorine dosing is stopped. However, under continuous chlorination mussels are constrained to keep the shell valves shut continuously. The mussels subjected to continuous chlorination at 1 mg/L showed 100% mortality after 588 h (*D. polymorpha*), 966 h (*Mytilus edulis*) and 1104 h (*Mytilopsis leucophaeata*), while those subjected to intermittent chlorination at 1 mg/L showed very little or no mortality during the same periods. Filtration rate, foot activity index and shell valve movement of *D. polymorpha, Mytilopsis leucophaeata* and *Mytilus edulis* decreased more than 90% at 1 mg/L chlorine residual when compared to control. However, mussels subjected to intermittent chlorination showed a similar reduction (about 90%) in filtration rate, foot activity index and shell valve movement during chlorination and 3% during breaks in chlorination. The data indicate that intermittent chlorination between 1 and 3 mg/L applied at 4 h on and 4 h off cycle is unlikely to control biofouling if mussels are the dominant fouling organisms.

Rajagopal, S., V.P. Venugopalan, G. Van Der Velde and H.A. Jenner. 2003b. Comparative chlorine and temperature tolerance of the oyster *Crassostrea madrasensis*: Implications for cooling system fouling. Biofouling 19(2): 115-124.

Crassostrea madrasensis is an important fouling oyster in tropical industrial cooling water systems. *C. madrasensis* individuals attach to surfaces by cementing one of their two valves to the substratum. Therefore, oyster fouling creates more problems than mussel fouling in the cooling conduits of power stations, because unlike the latter, the shell of the former remains attached to the substratum even after the death of the animal. However, there are no published reports on the tolerance of this species to chlorination and heat treatment. The mortality pattern and physiological behavior (oxygen consumption and filtration rate) of three size groups (13 mm, 44 mm and 64 mm mean shell length) of *C. madrasensis* were studied at different residual chlorine concentrations (0.25, 0.5, 0.75, 1, 2, 3 to 5 mg/L) and temperatures (30°C to 45°C).

Rajagopal, S., V.P. Venugopalan, G. Van Der Velde and H.A. Jenner. 2003c. Tolerance of five species of tropical marine mussels to continuous chlorination. Marine Environmental Research 55(4): 277-291.

The paper examines the relative lethal and sublethal response of five important tropical marine mussels (*Perna viridis, Perna perna*, *Brachidontes striatulus*, *Brachidontes variabilis* and *Modiolus philippinarum*) to different chlorine concentrations varying from 0.25 to 15 mg/L. The mussels were observed to co-exist in the cooling water circuits of a coastal power station that adopted intermittent chlorination as a fouling control technique. The five mussel species showed, in response to chlorination, 100% mortality at significantly different exposure times, indicating significant species-specific variability in chlorine tolerance. For example, at 1 mg/L residual chlorine, *B. variabilis* and *P. viridis* took 288 and 816 h, respectively, to achieve 100% mortality. The time taken for 100% mortality decreased with increasing chlorine residual concentration. The effect of mussel size (= mussel age) of *P. viridis, P. perna, B. striatulus* and *M. philippinarum* on mortality was significant between 1 and 5 mg/L residual chlorine, with larger mussels showing greater resistance than smaller ones. All mussel species showed progressive reduction in physiological activities when chlorine residuals were increased from 0 to 1 mg/L. However, species-specific differences in the relative rate of physiological activities were observed. Accordingly, relative reduction in physiological activities in response to chlorination was the lowest in *P. viridis* and the highest in *B. variabilis*. The data clearly indicate significant differences in the lethal and sublethal responses of the five mussel species to chlorination. The results, therefore, suggest that for effective fouling control, chlorine treatment against mussels has to be employed judiciously, depending on the mussel species involved.

Rajagopal, S., V.P. Venugopalan, G. Van Der Velde and H.A. Jenner. 2005. Response of mussel *Brachidontes variabilis* to chlorination. Chemistry & Ecology 21(2):119-132.

Brachidontes variabilis is a common fouling mussel species in cooling water systems of tropical coastal power stations. However, there are hardly any data available on the response of *B. variabilis* to chlorine, a commonly used antifouling biocide. Therefore, lethal and sublethal responses of this mussel to chlorine are of considerable interest to the industry. The response of mussels in terms of mortality pattern (LT 50 and LT 100) and physiological activities (oxygen consumption, filtration rate, foot activity and byssus thread production) in different size groups (with shell lengths of 7â€"24 mm) of *B. variabilis* was studied in the laboratory under different chlorine concentrations (0.25, 0.50, 0.75 and 1.00 mg/L for sublethal responses and 1, 2, 3 and 5 mg/L for mortality). The results showed that the exposure time for 100% mortality of mussels decreased significantly with increasing chlorine concentration. However, mussel size was not a determinant of its chlorine tolerance: all size groups tested (with shell lengths of 7.24 mm) took comparable exposure times to reach 100% mortality at a given chlorine concentration (1.5 mg/L). All size groups of *B. variabilis* showed a progressive reduction in physiological activities such as oxygen consumption, filtration rate, foot activity and byssus thread production, when chlorine residuals were increased from 0 to 1 mg/L. The data generated in the present work are compared with similar data available for other tropical fouling mussel species to see how far relative chlorine toxicity could have

influenced the relative distribution of the mussels inside the seawater intake tunnel of a power station at Kalpakkam in India. It is shown that in this insufficiently chlorinated system, the relative distribution of *Brachidontes striatulus*, *B. variabilis* and *Modiolus philippinarum* reflects the relative tolerance of the species to chlorine.

Rav-Acha, C., H. Shuval and E. Avisar. 1991. Formation of organochlorine compounds during chlorination of seawater in power plant cooling systems: A mutagenic assessment. MAP Technical Reports Series. FAO/UNEP/IAEA Consult. Meet. on the Accumulation and Transformation of Chemical Contaminants by Biotic and Abiotic Processes in the Marine Environment, La Spezia, Italy, 24-28 September 1990: No pagination.

Samples of Mediterranean Sea water taken at Tel Aviv (Israel) were chlorinated in the laboratory at various chlorine concentrations. Samples of power plant cooling sea water from the Reading power station were also collected. The organic components of these samples were isolated and concentrated using an Amberlite XAD-2/XAD-8 column, eluted with 95% ethanol. The ethanol extracts were assayed with the four Ames *Salmonella typhimurium* strains TA 98, TA 100, TA 102 and TA 104. The mutagenicity was correlated with the formation of volatile and non-volatile organochlorine compounds, as determined from gas chromatography (GC)) and Total Organic Halogens (TOX) analysis, respectively. All the tester strains gave positive dose-response curves with chlorinated sea water, with greater numbers of revertants in larger extract volumes. Statistically significant mutagenicity was found with all four strains in seawater chlorinated with 10 mg/L chlorine in equivalents of 100-250 ml water. However, seawater chlorinated with 2 mg/L chlorine only showed significant mutagenicity with the TA 98 and TA 104 strains. Chlorinated sea water discharged from the Reading power station only exhibited mutagenicity with strains TA 98 and TA 102, and not with TA 100 and TA 104.

Rhoderick, J.C., R.M Block, W.H. Roosenburg and R. Drobeck. 1977. Effects of chlorination to the American oyster, *Crassostrea virginica* at two temperatures. Research Association Southeastern Biology Bulletin 24: 80.

No abstract.

Richkus, W.A. and A.J. Lippson. 1975. An evaluation of the impact of the Morgantown Thermal Power Plant on macroplankton populations. PB-277082. M.M. Corp. Baltimore, MD (USA). Environmental Technology Center Report: 52 pp.

Studies of the effect of entrainment on macroplankton at the PEPCO Morgantown Steam Electric Station were conducted by the Chesapeake Biological Laboratory in 1972 and 1973. Densities of fish larvae declined significantly as a result of mechanical and thermal damage sustained upon passage through the cooling system. Amphipod and opossum shrimp appeared to suffer minimal entrainment damage. Chlorination increased ichthyoplankton mortality.

Roberts, M.H., Jr. 1978. Effects of chlorinated sea water on decapod crustaceans. Pp. 329-339. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects, Vol. 2. Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Roberts, M.H., Jr. and R.A. Gleeson. 1978. Acute toxicity of bromochlorinated seawater to selected estuarine species with a comparison to chlorinated seawater toxicity. Marine Environmental Science 1: 19-30.

No abstract.

Roberts, M.H., Jr., R. Diaz, M.E. Bender and R. Huggett. 1975. Acute toxicity of chlorine to selected estuarine species. Journal Fisheries Research Board Canada 32: 2525-2528.

No abstract.

Roberts, M.H., Jr., C.E. Laird and J.E. Illowsky. 1979. Effects of chlorinated seawater on decopod crustaceans and mulinia larvae. U.S. Environmental Protection Agency, EPA-600/3-79-031.

No abstract.

Roesijadi, G., D.M. Jacobsen, J.R. Bridge and E.A. Crecelius. 1979. Disruption of magnesium regulation in the crab *Cancer productus* exposed to chlorinated seawater. Marine Environmental Research 2(1): 71-84.

Exposure of the crab *C. productus* to chlorinated seawater resulted in alterations in hemolymph Na and Mg concentrations. At the highest chlorination levels, which approached the 96 h LC_{50}, regulation of both ions was essentially abolished. Reciprocal changes in the Na and Mg levels suggested an effect on the activity of the bladder wall, which was implicated in the regulation of hemolymph Mg in crustaceans. Exposure to 1.19 µg/ml applied Cl (0.68 µg/ml TRO) for 96 h resulted in a 4-fold increase in the NH3 excretion rate. Crabs also contributed considerable Cl demand to the exposure seawater. Measurements of TRO in the inhalant seawater and water exiting the crabs' branchial chambers indicated a reduction in TRO equivalent to 57% of that initially present in the inhalant water (0.51 µg/ml TRO). Measurements of NH3 concentrations in the exposure water indicated that NH3 in seawater was consumed in reactions with oxidants. This was especially evident at higher levels of chlorination. At 0.58 µg/ml applied Cl and above, chlorination resulted in near disappearance of NH3 from the water.

Roosenburg, W.H., R.M. Block and J.C. Rhoderick. 1977. The influence of chlorine produced oxidants on larval stages of the soft clam *Mya arenaria.* Association Southeastern Biology Bulletin 24: 82.

No abstract.

Rosales Casian, J.A. 1991. Seawater chlorination and the survival and growth of early life stages of northern anchovy (*Engraulis mordax* Girard), with reference to power plant cooling systems. Ciencias marinas. Ensenada 17(1): 99-117.

The viable hatch, survival, growth and lethal concentrations (LC_{50}) for early life stages of northern anchovy (*Engraulis mordax*) were examined after seawater chlorination. 36-hour eggs, and 1-day (yolk-sac), 3 day (yolk-sac absorption) and 5-day-old larvae were exposed to replicated concentrations of 0.0 (controls), 0.05, 0.1, 0.2, 0.5, 0.8 and 1.0 mg/L. Egg bioassays were of 24-hr duration only in static technique, and up to 12 days after hatching for larval series in semistatic technique. Water temperature was 18°C in all bioassays. The viable hatch of *E. mordax* eggs was reduced to 47.5% with 0.1 mg/L. A slight tolerance to chlorination with increased larval age was observed. Because of the high and fast mortality in greater concentrations than 0.5 mg/L, only growth data in less of 0.2 g/L were obtained. An exception was shown with 5-day larval series: survival in only one replicated treatment of 0.8 mg/L reached the twelfth day and permitted growth measuring; the mean standard length (6.04 plus or minus 1.24 mm) was smaller than that found in controls, the comparison of mean standard lengths in this series was significant, growth rates in controls were 0.44 and 0.39 mm/day, and with 0.8 mg/L growth rate was 0.26 mm/day. The 24 hLC_{50} indicated that the egg was the most sensitive stage with 0.114/mg/L. For 1-day larval series, the 24 hLC_{50}'s were 0.248 (no food) and 0.18 mg/L (Tetraselmis). For 3-day larvae, 24-hr LC_{50} was 0.236; 5-day larvae showed a greater value (0.799 mg/L), but at 96 hr it decreased to 0.29 mg/L.

Rosales Casian, J.A., I. Alfonso Hernandez and M. Gregory Hammann. 1990. Effect of seawater chlorination on the survival and growth of grunion (*Leuresthes tenuis* Ayres). En Condiciones de Laboratorio. Ciencias Marinas 16(2): 31-46.

21 bioassays were done to determine the chlorine effect on the survival and growth of 1, 4 and 16 day old *Leuresthes tenuis* larvae. In the laboratory, larvae were maintained under semistatic conditions at 17.8 degree, and fed with *Artemia nauplii*. After chlorination there was a decrease in survival with 0.2 mg/L Cl_2 and was null in less than two hours with 1.0 mg/L. The lethal concentrations LC_{50} after the first two hours for 1, 4 and 16 day larvae were 0.255, 0.15 and 0.119 mg/L Cl_2 respectively; the LC_{50} values at 24 h and 48 h were similar. These LC_{50}'s were low considering the dosing levels of chlorine that was added to water of power plant cooling systems. Growth data were obtained for low chlorine concentration only.(BDO)

Sanders, J.G. 1982. The effect of water chlorination on the toxicity of copper to phytoplankton. University of Maryland, Solomons, MD (USA) Report: No pagination.

The application of chlorine to estuarine waters usually results in oxidation of a finite quantity of organic carbon, averaging 35 micrometers. The oxidation may be salinity dependent; with one exception, all samples of > 5ppt. salinity showed a loss of carbon. The quantity of carbon oxidized is independent of the concentration of chlorine added, suggesting that only some compounds are attacked and oxidized. In every case,

the quantity of carbon associated with the smallest molecular weight fraction increased after chlorination. Copper distributions within various size fractions of natural organics did not change significantly after chlorination. The quantity of carbon oxidized is small in comparison to the total compellation capacity of estuarine waters.

Sanders, J.G. and J. Ryther. 1980. Impact of chlorine on the species composition of marine phytoplankton. Water Chlorination: Environmental Impact and Health Effects Vol. 3.; 3rd Conference. Colorado Springs, CO.: 631-640.

No abstract.

Sansone, F.J. and T.J. Kearney. 1981. Unusual chlorine kinetics of tropical seawater, and the potential environmental effects. PACON Conference: Pacific Congress on Marine Technology, Honolulu, HI (USA), 24-27 Apr: No pagination.

The kinetics of free halogen disappearance and end-product production following the chlorination of oligotrophic tropical seawater are more than a hundredfold slower than those reported for temperate coastal seawaters. Tropical seawater heat exchanger systems, such as in OTEC plants, thus require less chlorine for biofouling control than do comparable mainland facilities; this environmental advantage, however, is likely to be negated by the much longer residence time of the toxic free halogen. Caution is thus advised in the use of data from temperate waters to predict environmental chemical reactions and effects in tropical systems.

Santos, C. 1985. Zooplankton entrainment evaluation in a power plant station. Fourth Symposium on Coastal and Ocean Management -- Coastal Zone '85, 30 Jul-2 Aug 1985. (World Meeting Number 853 0607), Baltimore, MD (USA): No pagination.

No abstract.

Saragolia, M.G. and G. Scarano. 1979. Influences of molting on the sensitivity of toxics to the crustacean *Penaeua kerathurus.* Ecotoxicol Environmental Safety 3: 310-320.

No abstract.

Saravanane, N., K.K. Satpathy, K.V.K. Nair and G. Duraira. 1998. Preliminary observations on the recovery of tropical phytoplankton after entrainment. Journal of Thermal Biology 23(2): 91-97.

Chlorination is practiced for preventing biofouling in the cooling water systems of Madras Atomic Power Station. Results of laboratory experiments on phytoplankton recovery (as measured by absorbance and cell count) showed that the recovery time in process sea water effluents and condenser sea water effluents occurred after 3 and 5 days, relative to the natural intake water. Results also showed increasing dominance of a single phytoplankton species (*Thalassiosira* sp.) in the condenser as well as process water during the post recovery period. Significant differences in absorbance, gross primary productivity and total respiration rate were observed between intake water versus condenser water and intake water versus process water.

Scott, G.I. and D.P. Middaugh. 1978. Seasonal chronic toxicity of chlorination to the American oyster, *Crassostrea virginica* G. Pp. 311-328. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Scott, G.I., W.P. Davis, J.M. Marcus, T.G. Ballous and J.A. Dahlin. 1989. Acute toxicity, sublethal effects and bioconcentration of chlorination products, viruses, and bacteria in edible shellfish: A review. Grant EPA-R-813138. Prepared in cooperation with Research Planning Inst., Inc., Columbia, SC. Sponsored by Environmental Research Lab., Gulf Breeze, FL (USA).

The report identifies, synthesizes, and summarizes published scientific data concerning toxicity, sublethal physiological effects, and uptake/depuration rates of chlorine, viruses, and bacteria in edible marine shellfish of the United States. The summary may provide environmental managers with information related to coastal zone issues, such as point-source pollution permits, hazardous materials, material spills, and non-point-source runoff regulations.

Seegert, G.L. and A.S. Brooks. 1978. The effect of intermittent chlorination on coho salmon, alewife, spottail shiner, and rainbow smelt. Transactions of the American Fisheries Society 107(2): 346-353.

Coho salmon (*Oncorhynchus kisutch*), alewife (*Alosa pseudoharengus*), spottail shiner (*Notropis hudsonius*) and rainbow smelt (*Osmerus mordax*) were exposed for 30 minutes to residual chlorine. The alewives were tested at 10, 15, 20, 25 and 30°C, the salmon and shiners at 10, 15 and 20°C and the smelt at 10°C. Thirty-minute LC_{50} values were both species- and temperature-dependent. All species showed an inverse relationship between test temperatures and LC_{50} values. The range of LC_{50} values observed, with the test temperatures in parentheses, were coho salmon, 0.29 (20°C)-0.56 mg/L (10°C); alewife, 0.30 (30°C)-2.27 mg/L (15°C); spottail shiner, 0.53 (20°C)-2.41 mg/L (10°C); and smelt, 1.27 mg/L (10°C). Mortalities usually occurred within 24 h after exposure. Except for the 10°C spottail shiners, fish rarely recovered following loss of equilibrium. Concentrations resulting in no mortality were approximately 0.6-0.7 of the LC_{50} value.

Sheridan, P.F. and A.C. Badger. 1981. Response of experimental estuarine communities to continuous chlorination. Estuarine Coastal and Shelf Science 13(3): 337-347.

The effects of continuous chlorination (as NaOCl) on estuarine benthic organisms were investigated with plankton-derived experimental communities. Twelve consecutive studies were conducted, each of which consisted of approximately 60-day colonization

periods from flowing estuarine waters that continuously received nominal concentrations of 0.00, 0.47, 0.94 or 1.41 mg Cl-produced oxidant CPO) 1-1. Significant chlorination effects on numerical abundances of 8 dominant species were detected in data pooled over the 12 consecutive studies, although only 2 spp. were significantly affected in proportional abundance. There was also a significant decline in total numbers of individuals collected in chlorinated communities. Significant differences in short-term community structures were found in only 4 of 12 experiments and were related to changes in species dominance and increased toxicity due to extreme cold weather.

Sikka, H.C., K.C. Foote, J.I. Manji and E.J. Pack. 1979. Effects and fate of sewage chlorination products in phytoplankton. N.L.S.D. Syracuse Research Corp., Govt Reports Announcements. Issue 26: 68 pp.

The effects of seven stable chloro-organic compounds formed during chlorination of domestic waste-water on the growth of selected fresh-water and marine phytoplankton were determined. The uptake and metabolism of selected chloro-organic chemicals by the phytoplankton were also investigated. 3-Chlorophenol, 3-chlorobenzoic acid, 4-chlororesorcinol,5-chlorouracil, 5-chlorouridine, 6-chloroguanine or 8-chlorocaffeine at a concentration of 0.1 ppm, alone or in combinations of up to 4 chemicals, had no significant effect on the yield of *Scenedesmus obliguus*, *Selenastrum capricornutum*, *Microcystis aeruginosa*, *Dunaliella tertiolecta*, *Skeltonema costatum*, *Thalassiosira pseudonana*, and *Porphyridium* sp. 4-Chlororesorcinol and 5-chlorouracil were taken up by certain species but neither chemical was accumulated to a high level. The uptake of chlororesorcinol was considerably greater than that of chlorouacil. The uptake of 3-chlorobenzoic acid by the phytoplankton was negligible. 4-Chlororesorcinol was read

Smith, M.K., H. Zenick and E.L. George. 1986. Reproductive toxicology of disinfection by-products. Environmental Health Perspective 69: 177-182.

The chronic exposure of large segments of the population to disinfected drinking water has necessitated an evaluation of the health effects of the by-products of the chlorination process. This paper reviews the available information concerning the reproductive consequences associated with exposure to disinfection by-products. Four groups of compounds are discussed: the trihalomethanes, in particular chloroform; the chlorinated phenols; chlorinated humic substances; and the haloacetonitriles. In the pregnant female, chloroform and the 2- and 2,4-chlorophenols produced low levels of embryo- and fetotoxicity. Chloroform induced terata when administered by inhalation. The chlorinated humic substances and 2,4,6-trichlorophenol were without significant reproductive effects. The haloacetonitriles showed in utero toxicity, becoming more severe with increasing halogen substitution.

Sriraman, A.K. and R. Viswanathan. 1983. Effects of chlorinated cooling water discharges on the chemistry of estuarine waters. Mahasagar 16(2): 259-263.

The increasing tendency towards locating power plants at coastal and estuarine sites is in a large measure due to the practically unlimited amounts of cooling water available in these regions. This has also stimulated systematic investigations on the impact of the discharges on the chemistry of the receiving waters. A case in point is the use of chlorine for pretreatment of cooling waters. Available data indicate that chemical species which result from chlorination of seawater differ significantly from those of freshwater. In the present paper, these differences are discussed in relation to estuaries which contain varying proportions of freshwater and seawater. A critical account is given of the models proposed to explain the reactions, behavior and persistence of chlorine in discharge plumes in estuaries.

Stanbro, W.D. 1983. Chemistry of power plant chlorination. Report PB-84-127422., Applied Physics Lab, Johns Hopkins Univ., Laurel, MD (USA): 32 pp.

This report presents a summary of the present knowledge of chlorine chemistry as used for biofouling control in the electric utility industry. The level of the presentation is appropriate for the non-specialist who must regulate the use of chlorine in power plant cooling waters. The areas covered in this report are the practice of chlorination, fresh water chlorine chemistry, marine and estuarine water chlorination chemistry, analysis of chlorination products, models of chlorination chemistry and chemical dechlorination.

Stanbro, W.D. and M.J. Lenkevich. 1982. Slowly dechlorinated organic chloramines. Science 215(4535): 967-968.

Dechlorination of some organic chloramines with aqueous sulfite solutions does not take place instantaneously as previously assumed. Field dechlorination times on the order of hours for some compounds that are found in chlorinated effluents appear likely on the basis of laboratory studies. These chlorinated compounds are not detected by standard analytical methods in the presence of sulfite ion.

Stenton-Dozey, J.M.E. and A.C. Brown. 1994. Exposure of the sandy-beach bivalve *Donax serra* Roeding to a heated and chlorinated effluent. 1. Effects of temperature on burrowing and survival. Journal of Shellfish Research 13(2): 443-449.

The potential impact of the thermal plume from a nuclear power station on burrowing and survival of the bivalve *Donax serra*, which inhabits a nearby sandy beach, was investigated. Median lethal time and median lethal temperature were used to define the size-related upper thermal tolerance of *D. serra*. Small individuals would best tolerate heated effluent from the power station. Temperatures above 32°C were lethal to all sizes of *D. serra*. After extended exposure to temperatures between 24 and 29°C, 50% of the animals no longer remained buried. Because these temperatures occur in the thermal plume, such displacement from the sand can result in exposure to predation as well as possible stranding on the beach.

Stewart, M.E., W. Blogoslawski and G.R. Helz. 1979. Byproducts of oxidative biocides toxicity to oyster larvae. Marine Pollution Bulletin 10(6): 166-169.

Selected by-products which are produced upon chlorination or ozonization of seawater were examined for their effect on eastern oyster (*Crassostrea virginica*) larvae. The compounds bromate, bromoform and chloroform were studied at 0.05, 0.1, 1.0 and 10.0 mg/L. Repeated bioassays indicated that even at these low levels, all 3 substances produced some larval mortality. Oxidation by-products formed during chlorination or ozonization of power plant cooling waters may have adverse effects on the growth of marine invertebrates such as *C. virginica* during their delicate larval stages.

Stober, Q.J. and C.H Hanson. 1974. Toxicity of chlorine and heat to pink (*Oncorhynchus gorbuscha)* and chinook salmon (*O. tshawytscha*). Transnational American Fish Society 103: 569-576.

No abstract.

Stober, Q.J., P.A. Dinnel, E.F. Hurlberg, D.H. DiJulio, S.P Felton and R.E. Nakataini. 1978. Effects of seawater chlorination on marine organisms. Report No. UW-NRC-9. Department of Fisheries, University of Washington, Seattle, WA.

No abstract.

Sugam, R. and G. R. Helz. 1981. Chlorine speciation in seawater; a metastable equilibrium model for Cl^{I} and Br^{I} species. Chemosphere 10(1): 41-57.

A thermodynamic model for the inorganic, fast-reacting fraction of the total residual oxidant produced by chlorination in marine waters reveals that Br^{I} species are more stable than Cl^{I} species. At typical amino-N levels, HOBr, NBr_3, and $NHBr_2$ predominate. Data on organic byproducts of chlorination generally support the model calculations.

Sung, R., D. Strehler and C. Thorne. 1978. Assessment of the effects of chlorinated seawater from power plants on aquatic organisms. Final task report, May-September 1978. Technical Report. T.E.E. Div. Redondo Beach, CA (USA). 73 pp.

The report gives a detailed review of past and present research efforts on the effects of chlorinated seawater from power plants on aquatic organisms. It includes: (1) A characterization of chemical species contained in power plant seawater discharges; (2) a review of the amperometric titration method for residual chlorine determinations in seawater; and (3) an analysis of the toxicity of compounds formed by chlorination of seawater. The review concluded that (1) the toxicity of chlorinated seawater effluent is due primarily to various oxidant residuals produced by chlorination, rather than to residual chlorine itself; (2) the amperometric titration method is adequate to determine safe oxidant levels when identification of specific compounds is not required; (3) bromoform is a principal contributor to toxicity in power plant discharges (because of volatility and degradability, bromoform is not expected to be as toxic as chloroform); and (4) other compounds suspected of causing toxicity have not been clearly identified.

Tachikawa, M., T. Aburada, M. Tezuka and R. Sawamura. 2005. Occurrence and production of chloramines in the chlorination of creatinine in aqueous solution. Water Research 39(2-3): 371-379.

Occurrence and production of stable chloramines in the chlorination of creatinine, a constituent of perspiration and urine, in aqueous media were studied. Creatinine (5×10^{-5} M) was treated with free chlorine in aqueous solutions at molar ratios of 0.5–8 (chlorine/creatinine) at pH 7.0 at room temperature for several days. At lower ratios of chlorine, two stable *N*-chlorocreatinine derivatives, which were determined as dichloramine fractions by the DPD method, were isolated by HPLC and identified by EI-MS and ^{1}H-NMR. One was 2-chloroamino-1-methylimidazolin-4-one (creatinine chloramine) and the other was 2-chloroamino-5-hydroxy-1-methylimidazolin-4-one (hydroxycreatinine chloramine). In addition, the formation of methylamine was identified by GC-MS analyses of its imine derivative formed with pentafluorobenzaldehyde. Methylamine forms stable chloramines, which might be determined as mono- and/or di-chloramine fractions together with free chlorine by the DPD method in the reaction mixtures at higher molar ratios of chlorine. In practice, small amounts of methylamine (~19 μg/L) were detected in water samples collected from several swimming pools. Hence, methylamine may be an origin of elusive organic chloramine formed in the chlorination of swimming pools. A probable mechanism of the occurrence and processing of chlorination products of creatinine is suggested.

Thatcher, T.O. 1977. An effect of chlorination on the hatching of coon stripe shrimp eggs: so what. Proceedings National Shellfish Association 67: 71-74.

No abstract.

Thatcher, T.O. 1978. The relative sensitivity of Pacific northwest fishes and invertebrates to chlorinated seawater Pp. 341-350. In: Jolley, R.L., H. Gorchev and D.H. Hamilton (eds). Water Chlorination Environmental Impact and Health Effects Vol. 2 Ann Arbor Science Publishers, Inc., Ann Arbor, MI.

No abstract.

Thatcher, T.O. 1979. A morphological defect in shiner perch resulting from chronic exposure to chlorinated sea water. Bulletin Environmental Continental American Toxicology 21: 433-438.

No abstract.

Thompson, I.S., R. Seed, C.A. Richardson, L. Hui and G. Walker. 1997. Effects of low level chlorination on the recruitment, behavior and shell growth of *Mytilus edulis* Linnaeus in power station cooling water. Scientia Marina Vol. 61 (SUPPL. 2): 77-85.

Chlorination procedures are widely used to control biofouling in the cooling water systems of coastal power stations. However, relatively little is known about the ways in

which these procedures affect the ecology of major fouling organisms such as the mussel, *Mytilus edulis*. High concentrations of chlorine (8 mg/L), as sodium hypochlorite (NaOCl), lead to mortality of all planktonic larval stages, while lower concentrations (1 mg/L), produce changes in the swimming and crawling behavior of larvae in experiments conducted in non-flow through systems. The age and growth history of individual mussels collected from power station culverts were determined from the growth lines present in acetate peels of polished and etched shell sections. During periods of chlorination shell growth is severely reduced resulting in marked changes in shell structure and deposition. Consequently, growth rates of naturally occurring mussels were substantially greater than those occurring within the culverts. The information provided by this study, together with an ongoing monitoring programme of the natural periods of mussel settlement on artificial substrata, is currently being used to develop an appropriate chlorination protocol at Wylfa Nuclear Power Station, North Wales, UK. The use of mussels to evaluate the long-term effects of low level chlorination is briefly discussed.

Turnpenny, A. and C.J.L. Taylor. 2000. An assessment of the effect of the Sizewell power stations on fish populations. Hydroecologie Appliquee. 12(1): 87-134.

Sizewell A and B Nuclear Power Stations are located on the Suffolk Coast of East Anglia. The A station is a 650 MWe Magnox plant, completed in 1966 and operated by British Nuclear Fuels; the B station is a 1258 MWe pressurised water reactor (PWR), commissioned in 1995 and operated by British Energy Generation Ltd. Both power stations are direct cooled and rely on abstractions of cooling water (CW) from the North Sea: together they can abstract some 80 m^3s^{-1}. The water is passed around the plant condenser circuits and returned to the sea, along with reject heat and any chlorine residues from antifouling treatment. The abstraction of this water is accompanied, to some extent unavoidably, by entrained fish present either as ichthyoplankton (eggs, larvae and postlarvae of fish), or as fully-formed juvenile or adult fish which have to be removed by mechanical screening systems ("drum" screens) to avoid CW condenser blockage. The entrained ichthyoplankton passes through the entire cooling system and is discharged back to sea along with the heated water. The later life stages of fish and other material that become impinged upon the drum screens are removed from the water. At Sizewell B provision is made to return the more robust species of fish back to the sea alive. The results of these studies are frequently presented in this report in terms of Equivalent Adult Values (EAV's). The EAV method is a procedure where the numbers of fish of any age are standardized to the number that would be expected to be alive at the age when 50% of the stock would mature. Thus, if a fish matures at 3 years old, many millions of eggs or larvae may represent a single "equivalent adult", and the EAV will be a tiny fraction of unity, whereas a fish older than 3 years will have an EAV of greater than one. The purpose of the EAV method is to allow fish captured at any stage of their life cycle to be compared on an equal footing with fish of commercial size. It is important to note that the EAV method does not take account of density-dependent factors (such as rates of predation, parasitism, feeding success) that might tend to increase the survival, growth and reproductive rates of individuals left in the population when some of their competitors are removed. The values given should therefore be regarded as overestimates.

Van Der Velde, G., S. Rajagopal and H.A. Jenner. 1997. Sublethal responses of zebra mussel, *Dreissena polymorpha* (Pallas) to low-level chlorination: A laboratory study. Conference Proceedings: Seventh International Zebra Mussel and Aquatic Nuisance Species Conference.

Sublethal responses (filtration rate, foot activity index, byssus thread production and byssus thread strength) of different size groups of zebra mussel, *Dreissena polymorpha* (Pallas) exposed to seven different chlorine concentrations (control, 0.1, 0.2, 0.3, 0.4, 0.5 and 1.0 mg/L) were investigated in the laboratory. All size groups of mussels showed progressive reduction in physiological activities when chlorine concentrations were increased from 0 to 1 mg/L. Mussels exposed to greater than or equal to 0.1 mg/L showed considerable reduction in physiological activities when compared to control experiments (e.g., about 15% reduction in mean filtration rate at 0.1 mg/L). However, no significant differences in physiological activities were observed between 0.5 and 1.0 mg/L chlorine residuals (e.g., 89% and 93% reduction in foot activity index at 0.5 and 1.0 mg/L, respectively). The reduction in physiological activities of *D. polymorpha* was strongly correlated with the concentration of chlorine. Resistance of *D. polymorpha* to chlorine appeared to be lower than that found for other mussel species in The Netherlands viz., *Mytilus edulis* L. and *Myrtilopsis leucophaeta* (Conrad).

Vanderhorst, J.R. 1982. Effects of chlorine on marine benthos. Report EPRI-EA-2696. Battelle-Northwest Marine Research Lab, Sequim, WA (USA): 102 pp.

Studies were conducted to investigate the effects of chlorination on epibenthic communities in open microcosms and to evaluate open-microcosm methodology. A single experiment provided for two years of exposure to target concentrations of 10 and 50 ppB of chlorine-produced oxidants (CPO) in sea water. Continuous and intermittent chlorination regimes were used at each of the concentrations. The experiment was conducted in triplicate and included triplicate controls not receiving chlorination. There was an increase in the number of species for communities receiving each of the treatments, but there were significant ($p = 0.05$) differences in the rate of increase between intermittent and continuous chlorination regimes and between the two target concentrations within each of the regimes. Continuously chlorinated communities increased less rapidly in the number of species than did intermittently chlorinated communities. Communities receiving 50 ppB CPO increased in the number of species less rapidly than did communities receiving 10 ppB CPO ($p = 0.05$). There were significant ($p = 0.05$) effects on community complexity attributable to the distance between microcosms and the central head tank supplying all microcosms. Experimental substrates placed closer to the in-flow end of microcosms exhibited more animal species and fewer plant species than did experimental substrates placed closer to the out-flow end of individual microcosms.

Videau, C., M. Khalanski and M. Penot. 1979. Preliminary results concerning effects of chlorine on mono-specific marine phytoplankton. Journal of Experimental Marine Biology and Ecology 36: 111-124.

Static chlorination tests were conducted on 3 phytoplanktonic marine spp., *Dunaliella primolecta* Butcher, *Pavlova lutheri* (Droop) Green (= *Monochrysis lutheri* Droop) and *Phaeodactylum tricornutum* Bohlin. The specific response and the sensibility threshold of the algae tested: the chlorine LD50 for the least dense culture (103 cells .cntdot. ml-1) of *Dunaliella* and *Pavlova* is 0.4 and 4.0 ppm, respectively, while the growth of Phaeodactylum is reduced or ceases at a chlorine concentration of 0.6 ppm. Influence of cellular density: chlorine toxicity increases with decreasing cellular concentration (tests from 103-106 cells .cntdot. ml-1). The effect on chlorophyll a concentration is not affected when the mortality due to the chlorine injection is < 50%; the chlorophyll a concentration is greatly reduced for higher mortality. Influence of light: chlorinations conducted in the dark produce a lower mortality, for *Dunaliella*, than chlorinations conducted in the light; the mortality is lower as long as the cultures are kept in the dark. Chlorine as a disinfectant is applied at power plant cooling systems on estuaries and by the sea. The chlorination has an algicidal effect on fouling organisms but there is also a 90% decline in primary production.

Vreenegoor, S.M., R.M. Block, J.C. Rhoderick and S.R. Gullans. 1977. The effects of chlorination on the osmoregulatory ability of the blue crab, *Callinectes sapidus.* Association Southeastern Biology Bulletin 24: 93.

No abstract.

Waugh, G.D. 1964. Observations on the effects of chlorine on the larvae of oysters (*Ostrea edulis* L) and barnacles (*Eliminius modestus* Darwin). Applied Biology 54: 426-440.

No abstract.

Water Pollution Control. 1973. What you've always wanted to know about chlorination. Water Pollution Control. 111(1): 19-22.

The article deals with the types of chlorination used for pollution control, the chlorinators available and the control systems used. The primary purpose of chlorination is briefly reviewed. The article is intended to bring the knowledge contained in the former Ontario Water Resources Commission's manuals [cf. Journal American Water Works to Society] to a larger public.

White, W.R. 1966. The effect of low-level chlorination on mussels at Poole Power Station. Report No. RD/L/N17/66. Central Electricity Research Laboratories, Leatherhead, England.

No abstract.

White, W.R. 1969. Settlement and growth of mussels. Symposium on Marine Biology, Research Lab Memorandum No. RD/L/M 269. Central Electricity Research Laboratories, Leatherhead, England. Pp. 39-40.
No abstract.

Wickramanayake, G.B. and A.R. Gavaskar. 2000. Second international conference on remediation of chlorinated and recalcitrant compounds. Monterey, CA, May 2000. ISBN: 1-57477-094-2. Seven vol. set available for $399.50 from Battelle, 505 King Ave., Columbus, OH 43201-2693.
No abstract.

Williams, E.E. and B. Knox-Holmes. 1989. Marine biofouling solutions for closed seawater systems. Sea Technology 30(6): 17-18.
The patented BFCC antifouling and corrosion protection system--marketed by Biofouling and Corrosion Control Ltd., a University of Sheffield-based company that specializes in consultative work in this technical area--is intended to control biofouling in closed seawater systems on, for example, ships, offshore production platforms, desalination plants, and power stations. The antibiofouling efficiency of conventional electrolytic chlorine dosing, copper dosing, copper and aluminum dosing (a commercially available system), and a combined copper/chlorine BFCC treatment have been compared in field trials conducted in conjunction with the CEGB, the U.K. national power utility, and in independent tests at the University of Miami, Florida, in association with EPRI and Stone and Webster. The copper/chlorine (BFCC) system was found to be the most efficient at reducing fouling both inside steel pipes and on titanium heat exchange surfaces. Results indicate that the BFCC system is at least as effective as a conventional hypochlorite treatment at levels of chlorine between five and ten times less than those used in traditional hypochlorite dosing and at copper levels one-sixth of those required to kill macro-fouling.

Wilson, T.C. 1977. The effect of chlorine residuals on the blue rockfish (*Sebastes mystinus*), the rock prickleback (*Xyphister mucosus*) and the copepod (*Calanus pacificus*). Report No. 7846.
No abstract.

Winklehaus, C. 1977. Chlorination: assessing its impact. Journal Water Pollution Control Federation 49(12): 2354-2357.
A brief summary is given of the topics of the ``Second Conference on Water Chlorination: Environmental Impact and Health Effects`` held jointly by Oak Ridge National Laboratory, the U.S. Environmental Protection Agency, and the U.S. Department of Energy. Some 65 papers relating to chlorination were heard. The themes were: fresh water systems; marine systems; toxicity in aquatic systems; trihalomethanes;

waste water disinfection; health effects; industrial effluents; alternatives; and regulations, progress, and problems. The EPA overview of the regulatory aspects of chlorination was presented.

Woehrling, D. and G. Le Fevre-Lehoerff. 1997. Long-term series in ichthyoplankton and related species: Sole and sprat eggs and larvae at the French Coast of the North Sea during 20 years Ichthyoplankton Ecology, Fisheries Society of the British Isles Conference: No pagination.

Monitoring ichthyoplankton and environment at a control point in front of the nuclear power plant of Gravelines (French coast of the North Sea Southern Bight) since 1975 yields long-term series for eggs and larvae of sole (*Solea vulgaris* Quensel)

Xavier de Brito, A.P., I.M.R. de Andrade Bruning, I. Moreira and I. Loureiro. 1999. Occurrence of chlorinated pesticides in mussels of Guanabara Bay, Rio de Janeiro, Brazil. Marine Pollution Bulletin Toxicology In Vitro (Jul): 603-604.

Chlorinated pesticides are common Pollutants in the aquatic environment in coastal areas and estuaries. Guanabara Bay is a coastal area of great economical importance and leisure interest in the Brazilian Southeast Coastal It is surrounded by two cities, Rio de Janeiro and Niteroi, with a total population of about eleven million inhabitants. The Bay receives a daily discharge of chemical contaminants introduced with several tons of domestic, industrial and agricultural treated and non-treated sewage. Part of these contaminants may be incorporated by the living organisms of this ecosystem and consist of potential danger to human consumption. Present work investigates the contamination of some chlorinated pesticides in common mussels (*Perna perna*), from the Guanabara Bay. These mussels can be found in several points near the entrance of the Bay, where they either grow naturally or are cultivated by fishermen which make their living of this activity. Five collecting areas were studied and the concentrations of eight pesticides, namely HCB, gamma -HCH, total DDT, DDD and DDE, Aldrin, Dieldrin and Endrin were determined. The samples were collected twice a year, during the dry (August) and rainy (December) seasons of 1996. The mussels were manually collected, wrapped in aluminium foils previously rinsed with acetone, ethanol and hexane for pesticide analysis and kept frozen until reach the laboratory. After selection, 10 (ten) mussels of similar size (4-6 cm) composed one sample for each location. The muscle tissues were separated from the valves and were cold frozen-dried, so the water content was removed without loss of volatile components. The material was ground and homogenized and kept ready for the analysis under -10°C. A mussel sample (2g) was spiked with known amount of tetrachlorometaxilene (TCMX) and was Soxhlet extracted for 24 hours with pesticide grade hexane purified through Florisil columns.

Yamamoto, K., M. Fukushima and K. Oda. 1990. Effects of stirring on residual chlorine during chlorination of seawater containing ammonia nitrogen. Water Research 24(5): 649-652.

Stirring affected the concentration and proportions of residual chlorine during the chlorination of seawater containing ammonia nitrogen. At high stirring speed, the residual chlorine level rose in direct proportion to the dose of chlorine, then decreased to a minimum. At low stirring speed, the residual chlorine level began to decline before the peak of the break-point curve, which was flatter than the one obtained with high stirring speed. Regardless of the speed of stirring, monochloramine was the predominant species in the residual chlorine that remained after 1 h and the break-point was at the same chlorine dose. The amount of monobromamine produced was inversely related to the speed of stirring. Residual chlorine loss occurred primarily via the disproportionation of monobromamine to form dibromamine and ammonia nitrogen. Later, dibromamine and bromochloramine disappeared on reacting with monochloramine and only stable monochloramine remained. The degree of mixing of chlorine and seawater with ammonia nitrogen is of importance in evaluating the residual chlorine concentrations.

Yang, J.S. 2001. Bromoform in the effluents of a nuclear power plant: A potential tracer of coastal water masses. Hydrobiologia 464: 99-105.

Bromoform (tribromomethane, CHBr3), one of the trihalomethanes, is a chlorination byproduct in cooling water of power plants and industrial complexes. We used the distribution of bromoform in seawater to monitor the movement of cooling water from the Youngkwang Nuclear Power Plant (YNPP) located on the West Coast of Korea. Bromoform concentrations were highest, 124 μg l-1, in surface water near the outlet of YNPP and decreased linearly with distance from the outlet, mimicking the dissipation of cooling water discharged from the power plant. This byproduct of chlorination is thus a potential tracer of coastal water masses, due to its conservative behavior in the cooling water, low natural background in seawater, and easy analytical detection.

Yang, Y.-F., Z.-D. Wang, M.-X. Pan and N.-Z. Jiao. 2002. Zooplankton community structure of the sea surface microlayer near nuclear power plants and marine fish culture zones in Daya Bay. Chinese Journal of Oceanology and Limnology 20(2): 129-134.

The authors' surveys in May-June 1999 (two cruises) at six sampling stations near nuclear power plants (NPP) and marine fish culture zones in Daya Bay, Guangdong, revealed species composition, densities and body-size of the sea surface microlayer (SM) zooplankton (> 35 μm). Results showed that protozoans and copepod nauplii were the predominant components, accounting for 65.40% to 95.56% of total zooplankton in abundance. The size-frequency distributions showed that the frequency of micro-zooplankton (0.02-0.2 mm) reached 0.8235. The SM zooplankton community structure revealed in the present study was quite different from that revealed by investigations in the 1980s in Daya Bay. Difference of sampling method has important influence on the obtained zooplankton community structure. SM zooplankton consisted of micro- and mesozooplankton (0.2-2.0 mm), with micro-zooplankton being predominant. Some possible cause-effect relations between the zooplankton community structure and mariculture, nuclear power plants cooling systems and sampling method are discussed.

Yosha, S.F. and G.M. Cohen. 1979. Effect of intermittent chlorination on developing zebrafish embryos (*Brachydanio rerio*). Bulletin of Environmental Contamination and Toxicology 21(4-5): 703-710.

The primary objective was to determine whether chlorine adversely affects the hatchability of freshwater fish embryos and to what extent, if any, chlorine toxicity is modified by the ionic composition of the water. Contrary to initial expectations , chlorine, even at a relatively high concentration (1 mg/mL total residual chlorine), was not toxic to developing zebrafish embryos prior to hatching. However, chlorine in the presence of a mild external ionic stress (CaCl2 and MgCl2) significantly reduced the number of embryos hatched. Chlorine was toxic to newly hatched larvae in all solutions tested, whereas no mortalities of the newly hatched larvae occurred in any of the solutions in the absence of chlorine. Once again ionic stress potentiated the effects of chlorine.

Zeitoun, I.H. and J.Z. Reynolds. 1978. Power plant chlorination. Environmental Science and Technology 12(7): 780-784.

Cl is used to control slime in power plant cooling waters. Since Cl is toxic, its use is regulated. Ways of increasing the effectiveness of rules governing the use of Cl are discussed.

Zhang, X. and R.A. Minear. 2002. Characterization of high molecular weight disinfection byproducts resulting from chlorination of aquatic humic substances. Environmental Science & Technology 36(19): 4033-4038.

Aquatic humic substances react with chlorine to produce numerous disinfection byproducts (DBPs) during chlorination of drinking water. Although low molecular weight (MW) chlorinated DBPs have been intensively studied over the past several decades, relatively little is known about high MW chlorinated DBPs (above 500 Da) that may be associated with adverse health implications. In this work, carrier-free radioactive ^{36}Cl was introduced into a Suwannee River fulvic acid sample to label the chlorine-containing DBPs. By combining the fractionation techniques of ultrafiltration (UF) and size exclusion chromatography (SEC) with the detection of ^{36}Cl, UV, and dissolved organic carbon (DOC), the high MW region in the SEC-^{36}Cl profiles of the chlorinated sample with and without UF was defined. SEC-UV and SEC-DOC profiles were found to be approximately indicative of SEC-^{36}Cl profiles for the high MW region. The MW distribution shows that the high MW chlorinated DBPs were highly dispersed with an average MW around 2000 Da based on calibration with polystyrene sulfonate standards. The Cl/C atomic ratios of the high MW DBPs were roughly constant (0.025), which is much lower than those of the common known chlorinated DBPs.

Zhang, X.M. and R.A. Minear. 2006. Formation, adsorption and separation of high molecular weight disinfection byproducts resulting from chlorination of aquatic humic substances. Water Research Vol. 40(2): 221-230.

A significant portion of the unidentified disinfection byproducts (DBPs) in chlorinated drinking water can be attributed to high molecular weight (MW)-chlorinated DBPs (above 500Da) that may have adverse health effects. In this work, issues on the formation, adsorption and separation of high MW-chlorinated DBPs were investigated by introducing radioactive ^{36}Cl into humic substance samples. The results show that the amount of high MW-chlorinated DBPs during chlorination decreased with the increase of contact time from 1 to 120h, increased with the increase of pH from 5.5 to 9.5, and was less in the ultrafiltered samples from Suwannee River fulvic acid than from Suwannee River humic acid. The high MW-chlorinated DBPs were found to be effectively adsorbed by activated carbon and be possibly reduced to xCl^- by activated carbon, but not to be readily desorbed from the activated carbon. Those high MW-chlorinated DBPs were demonstrated to be incapable of resolution into discrete peaks by any of the three liquid chromatography columns studied. The significant implications of these results are discussed.

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Gasterosteus aculeatus (threespine stickleback)
- Thatcher (1978)

Girella nigricans (opaleye-Pacific)
- Hose et al. (1984)

Gobiosoma bosci (naked gobi)
- Bender et al. (1977)
- Roberts et al. (1975)

Hybognathus nuchalis (silvery minnow)
- Public Service Electic (1977)

Lagodon rhomboids (pinfish)
- Cripe (1979)

Leiostomus xanthurus (spot)
- Bellanca and Bailey (1977)
- Bongers et al. (1977)
- Liden and Burton (1977)
- Liden et al. (1980)
- Middaugh et al. (1977b)
- Public Service Electric (1978)

Leuresthes tenuis (grunion)
- Rosales et al. (1990)

Limanda limanda (dab-North Sea)
- Mehrtens and Laturnus (1999)

Lythrypnus dalli (blue-banded goby-Pacific)
- Hose et al. (1984)

Menidia beryllina (tidewater silverside)
- Morgan and Prince (1977)
- Public Service Electric (1978)

Menidia menidia (Atlantic silverside)
- Anderson et al. (1975)
- Bender et al. (1977)
- Bongers et al. (1977)
- Enstrom and Kirkwood (1974)
- Gift's Bioassay Work (1973)
- Hoss et al. (1977)
- Meldrim et al. (1974)
- Meldrim and Flava (1977)
- Morgan and Prince (1977)
- Public Service Electric (1978)
- Roberts et al. (1975)

Micropogonias undulatus (Atlantic croaker)
- Public Service Electric (1977)

Morone americana (white perch)
- Block et al. (1977; 1978)
- Burton et al. (1979a and b)
- Gullens et al. (1977)
- Hall et al. (1979b; 1981a)

- Laurer's Bioassay Work (1973)
- Morgan and Prince (1977; 1978)

Morone saxatilis (striped bass)
- Burton et al. (1979a and b)
- Hall et al. (1979b; 1981b)
- Hughes (1972; 1975)
- Middaugh et al. (1977a)
- Morgan and Prince (1978)

Mugil cephalus (striped mullet)
- Hoss et al. (1975; 1977)

Notropis hudsonius (spottail shiner)
- Seegert and Brooks (1978)

Oncorhynchus gorbuscha (pink salmon)
- Holland et al. (1960)
- Stober and Hanson (1974)
- Thatcher (1978)

Oncorhynchus kisutch (silver coho salmon)
- Buckley (1976; 1977)
- Buckley and Matsuda (1972; 1973)
- Buckley et al. (1976)
- Holland et al. (1960)
- Seegert and Brooks (1978)
- Thatcher (1978)

Oncorhynchus tshawytscha (chinook salmon)
- Holland et al. (1960)
- Stober and Hanson (1974)
- Thatcher (1978)

Osmerus morday (rainbow smelt)
- Seegert and Brooks (1978)

Paralichthys dentatus (summer flounder)
- Goldman (1978)

Paralichthys lethostigma (southern flounder)
- Hoss et al. (1977)

Paralichthys sp. (flounder)
- Hoss et al. (1977)

Parophrys vetulus (English sole)
- Thatcher (1978)

Pleuronectes platessa (plaice)
- Alderson (1969; 1972; 1974)
- Mehrtens and Laturnus (1999)

Pseudopleuronectes americanus (winter flounder)
- Anderson et al. (1975)
- Capuzzo et al. (1976a)
- Gentile et al. (1976)
- Goldman (1978)
- Goldman et al. (1978)

Sebastes mystinus (blue rockfish)
- Wilson (1977)

Solea solea (sole)
- Alderson (1969; 1974)
- Enstrom and Kirkwood (1974)

Solea vulgaris (sole)
- Woehrling and Le Fevre-Lehoerff (1997)

Sprattus sprattus (sprat)
- Woehrling and LeFevre-Lehoerff (1997)

Stenotomus versicolor (scup)
- Capuzzo et al. (1976a)
- Goldman (1978)
- Goldman et al. (1978)

Syngnathus fuscus (northern pipefish)
- Bender et al. (1977)
- Roberts et al. (1975)

Trinectes maculates (hogchoker)
- Margrey et al. (1976)
- Meldrim et al. (1974)
- Public Service Electric (1978)

Xiphister mucosus (rock prickleback)
- Wilson (1977)

Hydroid

Bimeria franciscana (colonial hydroid)
- McLean (1972)

Cordylophora caspra (brackish waster hydroid)
- Rajagopal et al. (2002c)

Phytoplankton

Asterionella japonica
- Gentile et al. (1976)

Chactoceros decipiens
- Gentile et al. (1976)

Chactoceros didymum
- Gentile et al. (1976)

Chaetoceros gracilis
- Browdy et al. (1998)

Chlamydomonas spp.
- Hirayama and Hirano (1970)

Coccochloris elebans
- Rainville et al. (1975)

Detonula confervacca
- Gentile et al. (1976)

Dunaliella primolecta
- Videau et al. (1979)

Dunaliella tertiolecta
- Gentile et al. (1976)
- Sikka et al. (1979)

Glenodinium halli
- Erickson and Freeman (1978)

Isochrysis galbana
- Erickson and Freeman (1978)

Microcrystis aeruginosa
- Sikka et al. (1979)

Monochrysis luther
- Gentile et al. (1976)
- Lamont-Doherty Bioassay Work (1973)

Nannochloris occulatus
- Bender et al. (1977)

Pavlova luther
- Videau et al. (1979)

Phaeodactylum tricornutum
- Goldman and Davidson (1977)
- Goldman et al. (1978)
- Videau et al. (1979)

Porphyridium sp.
- Sikka et al. (1979)

Pseudoisoochrysis paradoxa
- Bender et al. (1977)

Pyraminonas virginicu
- Bender et al. (1977)

Pyrodinium bahamense
- Azanza et al. (2001)

Rhodomonas baltica
- Gentile et al. (1976)

Scenedesmus obliguus
- Sikka et al. (1979)

Selenastrum capricornutum
- Harwood et al. (1989)
- Sikka et al. (1979)

Skeltonema costatum
- Erickson and Freeman (1978)
- Gentile et al. (1976)
- Hirayama and Hirano (1970)
- Lamont-Doherty Bioassay Work (1973)
- Sikka et al. (1979)

Tetraselmia syecica
- Bender et al. (1977)

Thalassiosira nordensholdii
- Gentile et al. (1976)

Thalassiosira pseudonana
- Erickson and Freeman (1978)
- Gentile et al. (1976)
- Sikka et al. (1979)

Thalassiosira rotula
- Gentile et al. (1976)

Thalassiosira sp.
-Saravanane et al. (1998)

The Department of the Interior Mission

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

The Minerals Management Service Mission

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

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

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