environmental circumstances), there is no assurance that the harmful effects that may be found would be present at the lower levels.

With inadequate information upon which to prepare an EIS, the expert must nevertheless come up with some judgment. All too frequently, there is neither a precedent to indicate what harm has resulted in an analogous case nor any scientific data which can be used with confidence to predict what is likely to occur in a particular situation. In such an instance the expert(s) preparing the statement are likely to speculate on theoretical premises, even though no facts are available to support such a theory. Such judgments, based upon efforts to protect the biota when adequate facts are not available, frequently bias the situation to an extent that when the facts later become available, it becomes evident that the precautionary protective measures adopted may have been too restrictive —perhaps unnecessary.

This situation demonstrates the need for two urgent steps. First, much more research is required to show the extent of damage to the biota caused under many different circumstances when environmental alteration occurs. In the second place, it must be realized that it is impossible at our present state of knowledge to adopt permanent regulatory measures or guidelines for protection of the biota against contaminants in the environment and related alterations brought about by increased industrialization. Rather, we must look upon most measures adopted now as provisional, subject to modification to make them more or less restrictive as research facts accumulate.

The following papers prepared by staff members of Northwest Fisheries Center give detailed discussions of some of the man-made environmental changes which are having, or will in the future have, potentially adverse impact upon the fisheries in the northeastern Pacific Ocean.

MFR Paper 1217. From Marine Fisheries Review, *Vol. 38, No. 11, November 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*

MFR PAPER 1218

Pollution in the Northeast Pacific Ocean

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Contamination of the northeast Pacific Ocean is generally thought to be below the level of serious pollution found in areas such as the North Atlantic Ocean and other oceans of the world. This does not mean that no problems exist or that this is an unusual area that has more self-purifying properties than other marine areas. Contamination does exist as evidenced by contaminated estuaries in various coastal areas and by the levels of chlorinated hydrocarbons, such as DDT and polychlorinated biphenyls, in the fat and blubber of marine mammals in the northeast Pacific. These animals obviously have been in contact with persistent contaminants, but whether this contact occurs on the high seas or in coastal waters is unknown.

The relative freedom of the northeast Pacific Ocean from pollution has been an accident of geography and timing. The settlement and industrialization of the area was slower and occurred later than on other U.S. coasts and even now are concentrated in only a relatively small proportion of the coastline. The prevalence of onshore winds and currents and the relatively narrow continental shelf with a sharp dropoff are also important factors. The shallow, cold Bering Sea will require special consideration when industrialization increases in the future. This lack of serious or recognized general pollution emphasizes the need to examine existing contaminants and the factors that may help to indicate if, when, and where problems may be developing. The information reviewed in this report includes research that is generally applicable and not specific to any single geographic area.

Emphasis in this report on pollution is directed toward the use of coastal waters of northwestern North America as a receptacle for man's wastes from domestic, industrial, and agricultural activities, in addition to factors involved in evaluation of effects on the marine life. Attention also is given to the history of attempts to minimize the input from these sources, an evaluation of the success and limitations of these attempts, and a discussion of current actions.

Oregon, Washington, Alaska, and

the Province of British Columbia were developed to utilize their raw materials, and early industrial development was related to these resources. Initial —and still major—industries were logging, mining, fishing, and agriculture. The population in the Northwest increased rapidly in the late 1940's and, in Oregon and Washington, coincided with a shift to manufacturing industries that required the cheap electrical power being generated from the dams on the Columbia River.

Wastes from these activities polluted some waters of Oregon and Washington, where major fish kills occurred in the 1930's. These kills were primarily in areas where pulp mills were discharging untreated waste into bays and estuaries. Other effects had occurred by that time. The oyster industry had deteriorated; logging practices and sewage discharges had damaged Pacific salmon, *Oncorhynchus* spp., spawning streams; saltwater beaches near metropolitan areas were polluted. Because of these conditions, the Oregon Sanitary Commission and the Washington Water Pollution Control Commission were established to eliminate problems in both fresh and salt water. Actions were delayed during World War II, but by the early 1950's, major pulp mills had changed their processes to decrease the amount of organic wastes discharged into the waters, and metropolitan communities began to treat sewage to remove much of the organic material. These actions thus eliminated significant amounts of obvious contamination in the waterways. In the 1960's, industries in urban areas started to discharge wastes into municipal sewer systems. According to Federal law, by 1977 industries must either discharge their wastes into sewer systems or have their own treatment plants.

Emphasis in water pollution control has always been on maintenance of water quality as defined by man rather than from the standpoint of the biota living in the water. This approach was dictated by lack of available knowledge about what is important to aquatic biological communities and to the individual species utilized by man. The results were that visible problems were treated but problems that were less obvious and more difficult to solve were not defined or controlled. An example from the less obvious problems was the slow recognition of the effects from recalcitrant materials, like chlorinated hydrocarbons, that degrade slowly and accumulate in the environment.

Both State and Federal governments have been increasing the restrictions on use of water for discharge of wastes. State laws vary in requirements, but the laws must meet objectives of Federal laws on water quality and pollution control. Amendments to the Federal Water Pollution Control Act were passed in 1972 to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The national goal is to eliminate the discharge of pollutants into navigable waters by 1985, with interim goals to be met earlier, such as treatment of industrial discharges by 1977, secondary treatment of effluents from sewage plants by 1978, and, by 1983, to have water quality which provides for the protection and propagation of fish, shellfish, and wildlife, and for recreation in and on the nation's waters. This law is a recognition and not a solution of problems of contaminants in our waters.

Technology exists now to permit us to intercept and treat waste discharges, to remove organic material and bacteria from the wastes, and to remove many other substances present in discharges. The problem remains of what should be done about materials not removed by present technology. Furthermore, future decisions may conclude that it may not be worth the cost and energy required to remove all of the environmental inputs from waste discharges, since some inputs may not be detrimental to the environment. In fact, some waste discharges may even be advantageous. Thus, we must be able to determine the types and quantities of materials that can be added to aquatic environments without detriment. If we do not make these determinations, efforts may be wasted on nonessentials. We also might still be adding traces of materials at concentrations that are detrimental to important marine biota, because of limited, and sometimes confusing, knowledge and understanding of the environmental impact from such contaminant materials.

ENVIRONMENTAL FACTORS

The approaches to investigation of the effects of contaminants in the oceans as contrasted to those in the coastal areas are different for several reasons. Work on ocean problems has ordinarily consisted of surveys to learn which contaminants have been transported from land. Little is known about which materials may be changing the marine environment. The routes of transport, whether by the atmosphere, by ocean currents, or by biological means, are of interest but they usually cannot be changed. The detection of contaminants in the ocean is a danger signal, but the principal measure that can be taken is to avoid significantly increasing the levels of contaminants in the environment. This leads to the need to investigate the land-sea and air-sea interfaces where the bulk of the contaminants are introduced and to determine which contaminants are causing problems. We are concerned, therefore, about contamination in coastal areas in relation to the ocean environment as well as about potential deterioration of coastal waters. The coastal environment receives the first and the greatest impact from use of water for waste disposal. Investigations of contaminants in coastal areas must include recognition of all materials that may become widespread contaminants as well as which contaminants are causing immediate problems in the coastal areas.

Although some contaminants introduced into coastal waters reach the open ocean by water transport, most will not build up to significant levels beyond the continental shelf unless the materials are transported by migratory species or in the atmosphere. Well-known examples are substances transported 1) by the atmosphere, such as chlorinated hydrocarbons—DDT and the polychlorinated biphenyls (PCB's), and 2) by man, such as petroleum oil and waste materials discarded from ships.

The rivers in the Northwest must also be taken into account in our consideration of coastal waters because of their importance as spawning areas for salmon, as sources of contaminants, and as critical factors in the physical environment of coastal waters. This is the case not only of estuarine areas, but also of the influence of rivers at the freshwater-saltwater interfaces in areas such as Puget Sound and along the Oregon and Washington coast affected by the plume of the Columbia River. Also, silt is introduced by the Columbia River and by much smaller streams, especially by the many glacial streams of the area. The silt is deposited when it contacts salt water and is continuously changing the nature of coastal sediments. The amount of freshwater runoff, which has wide fluctuations both seasonally and from year to year, changes environmental conditions and affects salinity, oxygen content, and temperature of coastal inlets. Man should hesitate to add additional problems, particularly from organic pollution, to areas with these naturally changing conditions.

Consideration of the impact of contaminants on marine animals must include the physical, chemical, and biological reactions of the material, often called fate and effects of contaminants. In this field not nearly enough background research has been conducted to furnish a basis to plan programs to answer specific questions about the effects on the animals of projected environmental changes. The complexity of what is a little understood system and the numerous possibilities for action and interactions mean that is very difficult to determine what we should be doing or not doing to our coastal environment. Since the biological communities of the coastal areas are living in a naturally rugged and changing environment, the species have developed the capabilities to adapt to variable conditions. The capabilities or mechanisms that permit species to adapt to new conditions play a major role in determining what and how much change man can introduce into the environment. On the other hand, we still know too little about these mechanisms to establish generalizations or principles that can apply to specific cases and permit accurate predictions of biological effects from different types of contaminants introduced into different environments.

Physical Environment

The dependence of aquatic organisms on their physical environment is well known, but some specific information should be mentioned to give a clearer picture of how contaminants may impinge on that environment.

The water in most of the coastal areas of the northeastern Pacific Ocean contains adequate nutrients and oxygen, the exceptions sometimes being some of the smaller inlets that have low rates of water exchange. Salinity varies in relation to proximity of freshwater flows. The fresh water has a very important role in such an environmental system because of its relation to stratification and currents as well as to effects on salinity.

Many contaminants are deposited in the sediments. These include both heavy insoluble materials that settle soon after introduction into the water and lighter materials that may adsorb to particulate matter and then settle. The physical conditions, the chemical environment, and the biological organisms present will determine what happens to the sedimented material. Possible events after sedimentation of contaminants include the following: 1) the material is bound to the sediments and is at least temporarily removed from the water system; 2) the material is taken up by organisms which then store it or transform it into soluble compounds which leach back into the water; or 3) the material rests on the surface of the sediments and, if large quantitles are added, changes occur in the character of the sediments and thus of the biological communities. The physical nature of sediments and the chemical and biological reactions in the sediments are important factors in determining the ultimate fate of contaminants, e.g., their transformations and their recycling, and in determining the capacity of an area to assimilate contamination.

The water dilutes and fractionates contaminating effluents as well as physically transporting them. Many contaminants that are soluble in fresh water will precipitate in salt water. This characteristic involves a complicated physical process at the interfaces between fresh water and salt water, which are horizontal rather than vertical interfaces in stratified waters. Many of these reactions at the interfaces can be studied on the basis of principles of physical chemistry and are important in determining the introduction of contaminants into the marine system and what plants and animals will come in contact with the contaminants. These reactions at the freshwater-saltwater interfaces result in deposition and buildup of contaminants in two areas, namely—the layer at the interface and the deposition areas in the sediments.

Water parameters that are critical for aquatic organisms are dissolved oxygen, temperature, and salinity. Kinne (1964) reviewed the effects of salinity and temperature on marine animals and Alderdice (1972) proposed methods to evaluate quantitatively the responses of marine poikilotherms to the above environmental parameters. These parameters determine the activity and the metabolism of the animals and influence the effects of many contaminants.

Oxygen Levels

The amount of dissolved oxygen required by the biota is related to the rate of metabolism, which is dependent on the temperature in these cold-blooded animals. The importance of maintaining adequate levels of dissolved oxygen is the reason that pollution control has for many years emphasized the control of the discharge of oxidizable organic material that will react and lower the dissolved oxygen content of the water. Depth and rate of water exchange also affect the levels of oxygen. Anoxic conditions in the Northwest have been reported in bays and inlets, especially during later summer and early fall in years of low water runoff. When the oxygen level is so low that the surface of the sediments becomes anoxic, benthic and epibenthic organisms are killed.

Water for migrating salmon should contain at least 5 ppm oxygen and spawning areas should be at higher levels. Salmon will avoid areas with low oxygen levels when possible and will delay their migration into streams with low oxygen levels until increased flow of water increases the oxygen content. Smith et al. (1972) studied the effects of sublethal levels of oxygen on activity and physiology of coho salmon, *O. kisutch*, and reported that the fish will adjust to some degree through use of anaerobic metabolism for energy. The adjustment to low dissolved oxygen also involved kidney function and possibly impaired excretory mechannisms of the salmon. Low oxygen levels increase the toxic effects of many contaminants, possibly due to the necessity of the animal to change from its normal aerobic to an anaerobic metabolism. Too little is known about the anaerobic metabolism of fish, however, to predict the interaction between specific contaminants and fish utilizing anaerobic metabolism.

Temperature

Both the range and the optimum temperatures vary for different species. Some species have a broad range of temperature in which they can live, although they may not function very well at the extremes. Salmonid species have a relatively narrow tolerance range. The rate of metabolism of all species increases with an increase in temperature. Specific physiological functions may also have an optimum temperature. Thus, the optimum temperature for production of antibodies in salmon is 15°C (Harrell et al., 1976). This plays an important role in the ability of the animals to resist diseases. Temperature also affects the total environment of the fish. Thus, lower temperatures permit higher levels of dissolved oxygen, and higher temperatures permit an increase in the levels of dissolved contaminants. Temperature levels will affect the toxicological impact of a contaminant by changing the metabolism of the animals. This interaction between temperature and the effects of a contaminant is discussed in the section on Toxicology of Contaminants.

Salinity

Salinity is as important as temperature and oxygen in the evaluation of the effects of contaminants on marine species. This may seem obvious but all too often it is not considered when effects of contaminants in coastal waters are evaluated. Such salinity effects are so important that data from freshwater studies cannot be directly applied to saltwater conditions. Salinity is a specific term that refers to the amount of the dissolved salts by weight. The bulk of the salts in normal sea water consists of a constant ratio of nine ions: sodium, potassium, calcium, magnesium, strontium, chloride, bromide, sulfate, and borate. The salts effectively buffer sea water and can react with many contaminants. Acids and alkalies added to a current of sea water will be neutralized at rates that can be calculated. Some contaminants will form insoluble salts in sea water and settle to the sediments, whereas others may become more soluble.

Marine animals vary in the range of salinity they can tolerate, and the optimum for many species will be different at different stages in their life cycles. An important factor in evaluation of results of bioassays for contaminant effects on marine animals is that two variables are being measured if the animals are in water that is not close to the optimum for the species because salinity levels other than optimum may have as much or more effect than the contaminant on the results of the bioassays.

CONTAMINANTS

As recently as the 1960's, the general practice to minimize contamination of our fresh water was to divert as much of the contaminated effluents as possible directly to salt water on the basis that wastes would be quickly diluted, and the tides and currents would transport them to the open ocean, where it was presumed that effects would be negligible. This practice ignored both the physical and chemical differences among pollutants and the lack of information about their possible effects on biological systems. However, effects from overuse were observed both on the receiving salt water and on the estuarine animals living there, and caution was exercised on the amount of waste added to the coastal waters of the Northwest.

An important use for water presumably will continue to be for disposal of some wastes, and we must be able to evaluate what contaminants can be added with reasonable assurance that their addition will not lead to degradation of important aspects of marine ecosystems. This judgment will require setting priorities, defining important aspects, knowing what contaminants can be added and the levels that can be permitted, and understanding interactions among different contaminants and the biota so that acceptable conditions can be established. Determination of the impact of wastes must include assessment of the combined effects of contaminants from all sources discharged into an area. This is difficult to do because all effluents will vary in composition and the information on composition is never complete.

The number and types of contaminants that enter waters is an almost infinite list and there are many ways to classify them. A basic division is to separate them into the hydrophilic or soluble materials and the hydrophobic or relatively insoluble materials. The contaminants are fractionated in water by their solubility and this separation directs their transport and routes in the environment. Some general characteristics of these two classes are given in Table 1.

The hydrophilic and hydrophobic compounds can be subdivided further into inorganic and organic contaminants. Inorganic materials important in the environment include metal ions and many nitrogen, phosphorus, and sulfur compounds. The organic materials include hydrocarbons, such as those from petroleum oil, and chlorinated hydrocarbons, such as many pesticides

Table 1.—Some characteristics and differences between hydrophilic and hydrophobic toxic compounds.

Hydrophilic	Hydrophobic
Watersoluble.	Relatively insoluble.
Often toxic and lethal but can be diluted or degraded rapidly to nontoxic levels.	Toxicity varies but often degrade slowly either in the environment or in animals and can be carried through various trophic levels.
Usually act via respiratory system and amount in water is critical.	Usually transported via food, although in some instances may be introduced via water. In these instances, the amount in the food usually can be orders of magnitude greater than in water before biological effects are noted.
Often catastrophic and animals have no chance to adapt.	Many animals adapt to presence and in 1 or 2 generations resistant populations may be built up.
Removal of source usually removed problem and repopulation depends on recruitment from adjacent communities. Exception: the contaminant that adsorbs to particulate matter is deposited in sediments and may be later recycled into the water.	Removal of source does not remove contaminant problem because of the slow degradation. Length of time necessary involves a combination of chemical and physical processes and of biological or microbiological degradation. Toxicity of the altered and degraded products is also important.

and the PCB's. Interactions between the inorganic and organic materials may transform insoluble to soluble compounds. Thus an insoluble zinc salt, which cannot be used as a nutrient, may bind with organic material by a process known as chelation and, changed to soluble material, becomes an available nutrient. Conversely, the binding between inorganic metals and organic materials may precipitate some metal contaminants and remove them from the water through sedimentation. The reactions of the insoluble compounds after they settle is then dependent on the environmental conditions and biota of the sediments.

Many soluble organic compounds undergo chemical and biological oxidation and add nutrients such as carbon, nitrogen, and phosphorus. They are potential pollutants when their concentration is exceedingly high and they are not rapidly diluted and dispersed. In this case the biological and chemical oxidations may reduce the oxygen level of receiving waters to levels dangerous to the aquatic communities in the area, especially in areas or during seasons with slow water exchange. If nutrients are present at too high levels, they may stimulate undesirable growth such as algae blooms and organisms forming slime. The control of water pollution in the past has been based primarily on removal of excess organic materials from sewage and industrial effluents.

Environmental effects from relatively insoluble compounds on the other hand usually are not as obvious. Many of these materials are slowly degradable and persistent contaminants that accumulate, circulate through the food web, and cause slow, chronic changes. These characteristics make insoluble organic contaminants of particular concern because the effects often are not noted until changes are drastic and possibly irreversible.

The interactions that occur between contaminants and naturally occurring compounds play an important role in potential biological effects, in degradation, and in transformations of the contaminants. These reactions affect the solubility and the toxicity of the compounds and also have an effect on potential biological transformations. Excellent reviews are available on physical and chemical reactions of organic compounds and their degradation by microbial, chemical, and photochemical systems in aquatic environments (Faust and Hunter, 1971) and on equilibria in natural waters (Stumm and Morgan, 1970).

Physical Transport and Distribution of Contaminants

Currents transport soluble contaminants, which tend to be distributed by convective mass transfer. Thus, the contaminants can enter the estuarine system via freshwater runoff. Many will be transported along with the freshwater layer, which is lighter and warmer than the salt water and will have an overall movement to the sea. The system is more complicated than this simplified description since the layers are not definitive and considerable mixing occurs. Many of the compounds soluble in fresh water are insoluble in salt water. Soluble compounds also adhere to particulate matter. In both of these cases transport of the contaminant will then be that described for insoluble material.

The insoluble materials are particles and their transport and distribution is determined by particle size and density as well as movement of water. The particles present will be not only from contaminants but also from natural sources, such as clays, metal compounds, organic detritus, and living microorganisms. Stumm and Morgan (1970) have applied principles of colloidal and surface chemistry to explain and understand the reactions that occur at the solid-solution interfaces of the particulate matter and the water.

Movement of particles is influenced by differences in salinity and by the gradient in electrolyte concentration between the outgoing upper layer of fresh water and the incoming lower layer of salt water. As particles sink, the salt water essentially retains them as the upper layer goes out to sea. Some of the material also accumulates at freshwater-saltwater interfaces. As the insoluble material enters salt water, electrolytes change the settling rate, which is faster for many materials in salt water than in fresh water. Thus, some particles settle, are removed from the water column, and become part of the sediments. Other particles will remain suspended in the salt water but are retained in the water column of the estuary. The above physical processes cause accumulation of many of the materials with the result that concentrations of many substances are higher in estuaries than in the open sea. A diagram of the physical fractionation of effluents is shown in Figure 1. It must be remembered that important as this process is, two other basic types of processes, biological and atmospheric, are also transporting and distributing contaminants.

Toxicology of Contaminants

Two questions that must be answered are how much and at what rate can a potentially toxic material be added to a marine system without causing adverse effects on the biota?

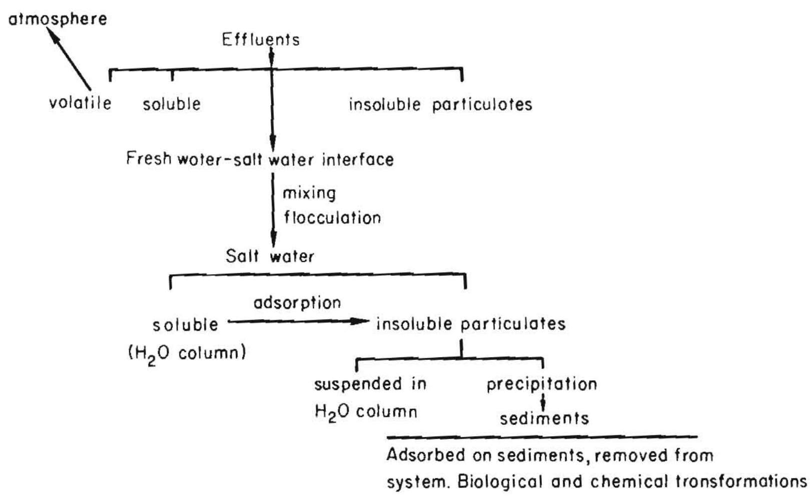

Figure 1.—Diagram of physical fractionation of effluents.

The answers will vary from one place to another depending on environmental conditions such as temperature, pH, salinity, rate of dilution by water movement, and the nature of other materials that are added to the same area. The physical and chemical environment of the area influences the reactions of the flora and fauna to the added material, the reactions and the fate of the contaminant, as well as the reaction between the contaminant and the plants and animals. Nevertheless, if we are ever going to predict the fate and biological effects of contaminants added to the environment, we must be able to apply some general principles and to make recommendations about safety or hazards to the aquatic environment when new industries plan to use water in an area, when decisions are made to minimize effluents from exisitng sources, and particularly when new compounds enter common domestic or industrial wastes in the future.

Contaminants can be characterized by the type of biological responses they cause. These responses may result from acute toxic symptoms that can rapidly kill animals; but if the toxic material is eliminated from the environment, the affected area can quickly recover and repopulation occurs. Short-term sublethal responses may affect behavioral and physiological functions of the biota and may result in indirect or direct death of the animals by making it more difficult for them to avoid predators, to obtain food, or to resist infectious diseases. Finally, long-term sublethal responses may affect populations by their effects on reproduction, such as a decrease in the quantity of fertile eggs, an increase in the time for hatching of eggs, and an increase in the number of abnormal (mutagenic) offspring from eggs that are hatched. Potentially dangerous long-term sublethal effects also result from compounds, such as the chlorinated hydrocarbons, that degrade slowly and the environmental amount continues to increase to a level that becomes dangerous to the biota, even though the incremental amounts added are below toxic levels.

Acute Lethal Effects

Until comparatively recently, much of the available information in the literature has related to acute lethal effects of compounds on fish and shellfish. Such effects have generally been measured on the basis of the death of one-half the animals under specific conditions, i.e., determining the LC_{50}, the concentration of a chemical in the water that will kill half of the animals in a specified time; or LT_{50}, the time required to kill half of the animals at a specified concentration. The data obtained can be useful if the limitations of the results are recognized and if the conclusions and interpolations that are made are not broader than are warranted from experimental limitations. One way to use the data is to apply mathematical equations that include factors for the detoxification of the specific contaminant by the animal and for the susceptibility of the species (Wilber, 1969).

Brown (1973) has summarized concepts of toxicology that apply to toxicological studies on the effects of contaminants on fish. These concepts are basic to evaluation of the conflicting information in reports on the toxic effects of contaminants. In addition to the confusion resulting from conflicting data and conclusions, three important aspects are rarely included in reports on lethal concentrations of contaminants. First, the condition, behavior, and recovery of the 50 percent that remain alive from LC_{50} experiments is usually ignored. The second neglected aspect is the overall response of the animals prior to death and the length of time before the first toxic symptoms are noted. The third is the autopsy report giving the immediate cause of death or lesions that may occur. Such information from lethal studies would help to identify both potential problems from effluents and specific contaminants and their toxic actions on test animals. Such information also could help to suggest possible problems with other species.

Many acute reactions on fish are related to interference with the respiratory mechanisms—whether by removal of oxygen from the water, or by damaging or coating gill tissue and thus preventing transfer of oxygen from the water to the blood stream. The effect on respiration is the reason that contaminants, such as DDT, will be lethal to fish and shellfish at the parts-per-billion level if they are in the water but will have little or no apparent effect at the parts-per-million level if introduced to the animals in food and go through the digestive process. This also illustrates an important toxicological concept: that the method of administration of a contaminant will alter results of tests and will determine both lethal levels and toxic effects of the compounds.

A brief mention should be made about some of the problems that exist in interpretation of data on lethal concentrations of pollutants. The aquatic animals, with the exception of marine mammals, are poikilotherms or cold-blooded creatures with body temperatures dependent on their environment; higher temperatures increase the rate of body metabolism and increase demand for oxygen. This temperature dependence can alter the results of toxicological studies depending on the design of the experiment. When, as is often the case, the experiments are of short duration and involve high concentrations of a contaminant, the animal will not have time to detoxify the contaminant. In this case, temperature will show a direct effect on toxicity and the contaminant will be classified as more toxic at the higher temperatures. On the other hand, if lower, more realistic, concentrations are used, the animal will have time to respond to the contaminant and his biochemical defense mechanisms may act to transform or store the contaminant and possibly render it biologically inactive. In this latter case, higher temperatures within the animal's tolerance range will increase the rate of metabolism and permit the animal to detoxify the contaminant at a greater rate. Under these conditions, the same contaminant would be classified as more toxic at lower temperatures. This instance also illustrates another important toxicological concept: that the dose level of a contaminant will alter results from bioassays.

The defense mechanisms mentioned above will affect other interpretations. for example, if two species are being compared, species one may show a greater sensitivity to the toxicant if the exposure is for a short time period. If the exposure time is extended, however, species two may not have less capability than species one to develop defense mechanisms. In the second instance the toxicity response curves will reverse, and the contaminant will be much more hazardous to species two.

Chronic Sublethal Effects

Sublethal effects of contaminants can be defined as manifestations of physiological, functional, biochemical, or behavioral change or impairment that do not directly kill individuals but do affect the ability of a species to survive. This definition includes such factors as disorientation, change in growth rate, metabolism, reproduction, disease resistance, change in food supply, ability to react to stress, and change in physiological parameters. Sublethal effects may or may not be harmful to survival of a species. When the effects are harmful they can be more dangerous to survival of the species than lethal effects because the species may have suffered irreparable damage before there is realization that the species has been damaged. Furthermore, knowledge of the sublethal effects of contaminants on species is required before the safety or hazard of a contaminant can be established. Information on sublethal effects is of special importance for those persistent contaminants that degrade slowly and thus may increase in the environment and in the food web. Until recently, very little work was done on chronic sublethal effects of contaminants on aquatic animals. Progress in this area is hampered by a lack of knowledge about many of the normal physiological and biochemical mechanisms and functions in cold-blooded animals. Less work has been done with marine species than with freshwater species because of the limited number of saltwater facilities available for such work. Nevertheless, work has started and this will be an area to watch in the future to learn what factors are critical for marine species and to define when problems may be developing in the marine environment.

EFFECTS OF POLLUTANTS ON MARINE LIFE

Pollutants can be broadly categorized by the type of reactions by which they affect marine life. These broad categories are chemical reactions, such as those associated with poisons like arsenic and cyanide; physical reactions, such as those caused by silt and other particulate matter, temperature changes, high or low salinity levels; and biological reactions, such as those associated with diseases (viruses and bacteria).

A pollutant may be more aptly regarded as a toxicant rather than a poison, which usually has the connotation of causing death. Thus, a toxicant may exert its effects and produce either a long-term or short-term nonlethal effect, which is either sublethal chronic or sublethal acute toxicity, respectively. The application of these definitions to the situation for a particular toxic compound can be quite arbitrary, because both concentration of the toxicant and time for the reaction will determine the biological effects. A high concentration of toxicant for a short time may result in death, while a low concentration for a long time may result in the fish being able to adapt to the presence of the toxicant. Dose-time relationships cannot be be interpolated except for a very small range.

The interrelationships involved with pollution and biological systems can be diagrammatically represented (Fig. 2). The biological effects of a foreign substance from pollution is influenced by the stress of variable environmental conditions, the nature of the foreign substance, such as chemical structure of the pollutant, and the dose of the compound in the body of the affected organisms and time of exposure. Conditions of the environment affect the physical and chemical states of pollution substances, such as degree of solubility in water, adsorption on particulate matter, and ionic conditions of mineral substances. The concentration of toxic substances from pollution in aquatic environments also depends on the physiochemical nature of the environment, such as available particulate matter for adsorption, precipitation as solids, and diffusion characteristics of bodies of water, as well as quantities of the substances entering the environment and their rates of entry. The overall pattern of interrelationships is highly complex in a real sense.

Short-Term Effects

The most obvious and severe forms of activity of a toxicant from pollution are those which result in death of marine life after relatively short exposure. A pollution toxicant, in this instance, produces acute lethal effects, with death resulting from a variety of reasons or factors.

Physical interaction of certain chemical substances and particulate matter with gill surfaces of fish can cause suffocation and death. Chemical products, such as synthetic polymers, and natural substances, such as tar globules

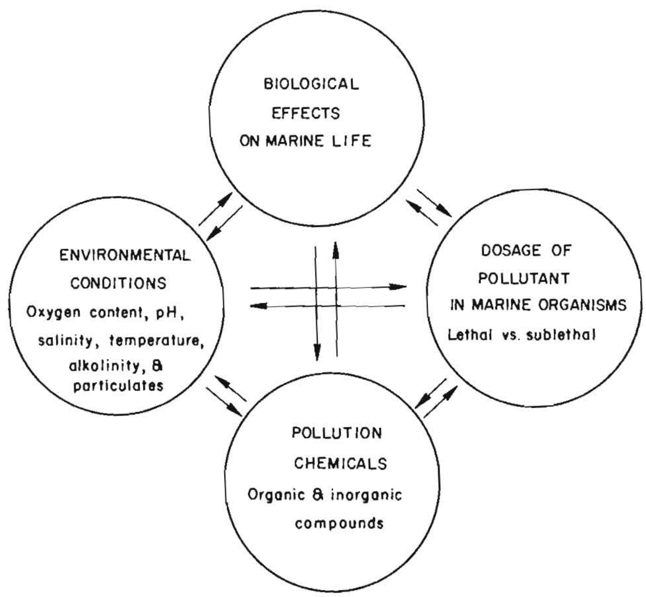

Figure 2.—Interrelationships of aquatic pollution, environmental conditions, and marine biological activities.

and heavy oils from petroleum, can form barriers to oxygen by adhering to gill surfaces. Finely divided particulate matter, like that found in soil silts and mineral or clay sediments, can also adhere to gill surfaces. These products and substances, if in great abundance in an aquatic environment, can overcome the natural cleaning action of mucus-secreting cells in gill epithelia, thereby barring passage of oxygen. Some compounds cause damage to gill rakers and thus cause abnormal respiration.

The gills of fish are the main interceptors of pollutants dissolved in water. Because of the relationship of dissolved pollutants to gills, the biological effects of the pollutants in marine animals may be complex and very difficult to determine. In addition to the physical interactions of pollutants with the gills, chemical reactions also occur. A pollutant may dissolve in the mucus on the gill surfaces and produce a reaction product, which may render the gill function inoperable. Other pollutants, because of peculiar properties, may be easily transported through the gill membranes and into the blood stream. The rate of entry of a pollutant into a fish by this mode is probably faster than any other natural mode of entry; therefore, a fish may concentrate larger amounts in its body tissues from lower environmental levels than it would if the pollutant entered via feeding during a comparable time interval.

Fish vary in their reactions to turbid conditions. Some freshwater fishes can tolerate very turbid conditions, e.g., 100,000 ppm sediment levels, whereas other marine organisms are very sensitive. Adult fish are comparatively tolerant of suspended mineral particles, although abrasion of gills and skin occurs. Eggs, fish larvae, and aquatic insects are not so tolerant. Rainbow trout, *Salmo gairdneri*, can tolerate 30 ppm silt, but incur mortality from 90 ppm. Shellfishes, which are filter feeders, are quite susceptible to the action of silt. In heavy suspensions of mineral particles, the feeding process of oysters can be inhibited completely. Highly turbid water can also block light and reduce the level of photosynthesis.

Contaminants can have a variety of lethal effects. Some chemicals produce paralysis, which can lead to secondary effects such as failure of respiratory function, gastrointestinal dysfunction, and failure of kidney, heart, and general vital organ functions. Aside from these failures, paralysis and even partially impaired mobility can increase susceptibility to predation. Some chemicals acting on the nervous system of fish might produce harm to vital organs and functions, thereby altering normal behavioral patterns essential for survival. Chemicals, such as calcium, may alter the capacity of a fish to properly adjust salt balances in blood and tissue cell components, thus upsetting the vital movement of body-building substances and substances from breakdown of nutritional components for energy. Permeability of cellular membranes is vital to life processes, and it is alterable by calcium salts. Other heavy metal salts may also react with membranes.

Some heavy metals such as iron and zinc are required to sustain life; however, when these and other metals are in solution in excessive amounts, a variety of abnormal effects can arise in the fish. The effects may become lethal if the fish cannot rid themselves of the heavy metals. Young Atlantic salmon, *Salmo salar*, have been found sensitive to soluble inorganic copper and zinc, with an incipient lethal concentration of 48 parts per billion (ppb) of copper sulfate and 600 ppb zinc sulfate in the water. If copper and zinc are present together, young salmon die much faster than if they were in contact with water containing either metal salt separately (Sprague, 1964). This illustrates the yet to be discussed phenomenon of synergism, where fish can be subjected to effects of several contaminants simultaneously. Shellfishes are also very sensitive to dissolved zinc and copper. Dissolved cadmium and organic mercury are among the more toxic metals toward marine fishes. There are other related effects of these contaminants in the environment where our knowledge is very limited.

Organic chemical pollutants, which can enter fish through the food web and be carried in the lipid components of the body, can potentially exert a variety of actions on the numerous biochemical entities in fish (Johnson, 1968; Grant and Schoettger, 1972). For instance, an aquatic environmental substance may antagonize a hormonal system in fish, with an attendant wide range of consequences, several of which could produce death. Hormones regulate the water balance in fish tissues; hormones may regulate urine flow and other vital processes that rely on water balance. Water balance, for example, may affect vital tissue and cellular salt balances by indirect action or by dysfunction of the fish endocrine system. The endocrine system and its activity are related to metabolism, which in turn is affected. Although grossly oversimplified, these examples illustrate the kinds of interactions that are involved in the highly complex nature of the biochemical workings of fish, once organic pollution substances begin to exert their effects.

Another short-term effect of contaminants is related to problems of survival of early life stages of marine organisms, such as sac fry and shellfish larvae. Research on the effects of an insecticide, dieldrin, in sea water on the development of crab larvae has shown that survival was not affected during the first crab stage, but there were 15-27 percent higher mortalities during development to the postlarval stage compared to controls (Epifanio, 1971). Also, results of experiments on an insecticide, DDT, with trout and guppy showed that there was eventual mortality of developing larvae, generally at the sac fry stage when the last remnant of yolk was being absorbed (King, 1962; Macek, 1968).

Some of the very vital areas of the biochemistry of fish, wherein toxicants could exert irreparable damage, include the energy utilization systems, body building processes, and processes of elimination of waste products from the energy utilization and body building processes. The operation and chemistry of the functions and processes associated with body energy, body building, and waste elimination are not completely understood, but pollution toxicants that come in contact and can react with any of the essential biochemical intermediates of these processes potentially can produce an effect on the physiology and behavior of the fish. If such reactions occur, the next step would be to show whether the effect is significant for prediction of harm or damage to the fish.

Nature has provided, in many instances, for alternatives in natural processes in the event that failure occurs in another process or function. All is not known about the natural processes and functions occurring in bodily systems of fish; therefore, to assess the true biochemical and biological impact of a pollutant chemical upon marine life is often difficult, laborious, long-term, and highly specialized.

Long-Term Effects

Sublethal effects of contaminants on marine life are often insidious and difficult to recognize; yet these effects may produce widespread damage to communities of biota. Sublethal effects may be either direct or indirect, with the indirect effects often more difficult to measure than direct effects, because of the long time needed for positive observations of the indirect or secondary effects.

In discussing the short-term effects above, the possibility was mentioned that direct interactions of toxicants with the fish nervous system can lead to indirect effects on the function of muscles of fish and thus decrease mobility. Although this is a sublethal effect, this situation leads to a secondary lethal effect in that the toxicant renders the creature easy prey to predators.

Another kind of long-term, indirect effect is a decrease in the viability of marine organisms to reproduce. Here, too, no lethal effects are observed on a primary population, but abnormal patterns of numbers of progeny, low rates of development or growth, and deformities of body structures can be caused by certain toxic substances. The viability of species may be affected by alterations in bodily processes for sperm production and the ability of eggs to become fertile. Toxic substances can be transmitted by progenitors and become endogenous to the eggs. In this way, lipid soluble toxicants can be present in the larvae and the very early stages of development of marine organisms (Johnson, 1968).

There is evidence for both long-term lethal and nonlethal effects that can occur in the progeny of fish that have had prior exposure to a toxicant. Where all parents of three generations of laboratory-reared fish were exposed to an insecticide, the first and third surviving progeny (F_1 and F_3 generations, respectively) tended to be less sensitive to DDT than the corresponding unexposed "control" progeny, whereas the second generation fish (F_2 generation) was more sensitive than its control generation (Holland and Coppage, 1970). Deaths occurred in each generation group, but greater percentages died in the more sensitive F_2 generation. Much more work along similar lines is needed for people to understand what the effects of contaminants might be to fish in the wild over many generations. The indications are that the early stages of life, as suggested before, are more susceptible to certain contaminants than the more resistant adult forms of marine life. Moreover, little is known about possible selective actions of the many types of chemical pollutants and other contaminants leading to this phenomenon.

An important direct sublethal effect of a toxicant deals with the phenomenon of "homing" in anadromous fishes. The ability of the fish to sense the proper direction of migration or to locate its home stream, when returning from years in the open ocean, can conceivably be impaired and perhaps totally limited by reactions due to localized environmental pollution. Because the exact processes of homing in these fish are not yet well understood, the ability of researchers to pinpoint evidence for direct toxic effects on the essential aspects of the homing process is difficult.

Some pollution toxicants may cause inhibition of growth rates of maturing fish. Such sublethal effects due to diminished natural food sources (an indirect exogenous environmental effect) or simply poor food utilization (an indirect endogenous effect) can restrict growth of organisms. This kind of biological effect of pollution could have disastrous economic effects on a commercial fishery if allowed to continue unabated.

Another potential long-term sublethal effect deals with the question of disease resistance of fish. What effect could a chemical pollutant have on lowering the resistance, for example, towards a viral infection in a community of flatfish? An increase in the incidence of tumors in flatfish in the San Francisco Bay region has been suspected of being caused by virus; the incidence was also suspected to be pollution oriented (Cooper and Keller, 1969). The bacteria *Vibrio anguillarum*, which causes vibriosis in fish, has been diagnosed as the cause of deaths of salmon raised in saltwater pens in Puget Sound, Wash. (Novotny, 1975; Harrell et al., 1976). It is not known whether or not pollutants play a role in such incidents. The widely publicized environmental pollutants, PCB's, were reported to reduce disease resistance in ducks. Evidence is found for the impairment of immunological processes and disease resistance in higher animals, but little definitive work of this kind has been done with fish.

Additional Considerations

Migratory marine organisms often are forced to undergo particular natural physiological adjustments and adaptations. A short-term adjustment is associated with diel periodicity, which can influence certain physiological processes like those related to day-to-night and night-to-day adjustments. These short-term adjustments in an organism's body are referred to as acclimatization. A much longer adjustment phenomenon in fishes relates to those that may occur once or perhaps only a few times during a life span. This latter adjustment is referred to as adaptation and involves such physiological adjustments as related to saltwater-to-freshwater transitions or cold-to-warm water transitions (temperature adaptation). Both acclimatization and adaptation pose physiological effects and stresses in marine organisms. The interactions of pollution toxicants with the various physiological processes in marine creatures could possibly influence the rates of acclimatization and adaptation. If these rates deviate significantly from the normal rates of adjustment, then potential harm may be incurred in the life processes of the creatures involved.

A third type of adjustment made by fishes, and marine organisms in general, can be called genetic adaptation. This type was alluded to, above, in discussing effects on viability of the organisms. Experimental evidence on freshwater species has demonstrated what could be regarded as induced genetic adaptation, i.e., the progeny of fishes exposed to sublethal levels of a toxicant are more resistant to lethal levels than were their progenitors at the same life stages. This was shown from studies on the effects of DDT insecticide on guppies (King, 1962) and trout (Macek, 1968).

The molecular structure of chemicals within a class can vary, causing different concentrations of the compounds in different tissues and organs of fish. Such variation in chemical structures are found in gross mixtures of industrial products like PCB's, petroleum hydrocarbons, and synthetic polymers. Polychlorinated biphenyls were found to accumulate selectively in various tissues of coho salmon; the accumulation was dependent on the degree of chlorination on the biphenyl molecules (Gruger et al., 1975). A similar selective accumulation may be found for polycyclic aromatic hydrocarbons from petroleum products, although in this case metabolic reactions may play a role in their elimination.

An extremely important concept in assessment of toxicant effects is that of synergism (Weiss, 1959; O'Brien, 1967). An example was mentioned above. A definition of synergism is the "cooperative action of discrete agencies in such a manner that the total effect is greater than the sum of the effects taken independently." There are numerous examples of synergistic action of one chemical compound with another in biochemical systems. When determining the biological effects of pollution compounds, it is important to include the additional consideration that other compounds, either natural or foreign, can react with the toxicant and reduce its effective concentration and thus produce a corresponding decrease in toxic symptoms. The potential for synergistic activity of pollutants is great in highly industrial as well as in mixed industrial and agricultural areas, where a multitude of different pollutants are apt to be present in the aquatic environments.

In contrast to synergistic activities, the phenomenon of antagonism is important as well. Antagonism is the opposition in physiological action, especially in relation to the interaction of two or more substances, such that the action of any one substance on living systems is modified. This is an instance where, for example, the total effect of pollution toxicants is less than the sum of the individual effects of the toxicants when determined independently.

To provocatively illustrate how antagonism could operate in marine life, we can consider the following possibility: Two fish of the same species, one containing a particular insecticide and the other free of the insecticide, migrate into an estuary containing 100 ppb of certain dissolved residues of petroleum oil products. The residues of oil products find their way into the tissues and cells of the two fish and interact with the physiological processes. In one fish, these processes are already affected by the insecticide. The fish containing the insecticide is apparently healthy, and an analysis of its body tissues shows a maximum of one ppm of residues of the oil products. The fish that does not contain the insecticide appears to be in poor health and perhaps near death, and analysis of its tissues shows a maximum of 100 ppm of the residues. The insecticide could have exerted an antagonistic effect on the activity of the petroleum residues, resulting in a protective action with no apparent effect on health. Without the presence of the insecticide in the body, the fish was severely affected. Another clue in this illustration that the insecticide is antagonistic is that the fish had less oil residues than the fish free of insecticide. An explanation of the effect could be that particular defensive biochemical processes had been activated to deal with the presence of the insecticide and at the same time are able to interact with the petroleum residues and cause their catabolism. Such activated or induced biochemical processes are commonly observed in studies of drug and insecticide actions (Mayer et al., 1970; LaDu et al., 1971).

The role of lipids, or body fats, in modifying the effects of pollution chemicals appears to be an important part of the physiological processes that take place in marine organisms. Many pollutants that are lipid soluble are expected to be located in the body where lipids are also found (Holden, 1962; Johnson, 1968). There are aspects of the role of lipids in such a phenomenon, however, that are not clearly understood. Just because a pollutant is found in a marine organism, it is not necessarily true that there is or will be a toxicological problem. Fish can contain lipid soluble contaminants, whose activities are influenced by their presence in lipid deposits. For example, fish have been shown to contain high concentrations of DDT and its metabolites in lipid deposits without obvious effects. Fatty fish may have quite different problems, compared to lean fish, for the same level of a contaminant in the environment.

Some research has shown that there is either no direct relation or a poorly correlated relation between the lipid content and the concentration of organochlorine compounds in fish tissues and organs. It was suggested that a substance other than lipid has a high affinity for those organochlorine compounds (Grzenda et al., 1971). Perhaps the substance with a high affinity for lipid soluble pollutants is lipoprotein, whose role is little understood for fish. The mode of transport of such pollutants in fish is a problem of current research interest, and the association of the lipid soluble compounds to the lipophilic moieties of natural biochemical components is an important part of that problem.

Another aspect of the effects of compounds from pollution on fish is related to a correlation of prior exposures of the compounds to fish with the establishment of "susceptible" and "resistant" strains of fish. This phenomenon may not necessarily be genetic in nature, because sometimes there are not long-lasting or multiple generation effects. One argument used to explain susceptible fish is that the fish may possess nontoxic, low concentrations of toxic substances of such level that when the fish are placed in an environment containing other toxic substances, the additional effects of the latter can tip the scales in favor of the appearance of toxic symptoms. This would be a case of the sum of effects of toxicants producing symptoms that are not observable in fish containing relatively low levels of total toxicants. Synergistic activity may be another argument to differentiate susceptible fish from resistant fish, if the susceptible fish already contain toxicants.

On the other hand, the existence of resistant strains of fish may argue that prior exposures of these fish to toxic substances has activated the natural defense systems in the fish (e.g., via certain enzymes, as so-called mixed-function oxidases, in tissue cell components) that can intercept new toxicants that enter the body; such systems may not be active in the corresponding susceptible fish. This also may be an argument for the involvement of the phenomenon of antagonism, which may be operative in resistant fish. To illustrate how confusing the situation can be, research has shown that DDT and methyl parathion (insecticides) are more toxic to resistant fish than to susceptible ones. The conclusion was made that there are differences in the mode of action between the insecticides and the production of a greater overall stress from mixtures of the compounds (Ferguson and Bingham, 1966; Ferguson et al., 1966). At the present time, we do not fully understand the mechanisms involved in the actions of toxic compounds in fish. Much remains to be investigated relative to synergism, antagonism, resistant strains, and susceptible strains.

Finally, age of fish can be a factor in the toxicity of chemical substances. Work on four salmonid species has demonstrated that very young fish, e.g., 0.5-gram size, are more affected by certain insecticides than are fish slightly older, e.g., 1.6-gram size (Post and Schroeder, 1971). Age differences may be a factor, too, where pollutants appear to accumulate in some fish without major consequences because of differences in ability to eliminate pollutants by metabolism (Bache et al., 1972). An obvious correlation to age is size or weight, which indeed relates to the capacity for storage of pollution chemicals.

In conclusion, the interrelationships of chemical substances in aquatic living systems are extremely complex. Evaluations of the biological effects of toxic substances from pollution involve numerous considerations and assessments of interactions among natural marine life processes with the additional impact of the foreign compounds.

CONTAMINANTS DISCHARGED IN THE NORTHEAST PACIFIC

The principal sources of effluents discharged into the estuaries and marine waters of the Northwest are pulp and paper plants, municipal sewage, chemical and metal plants, food processing, rivers, and land runoff. The total amounts of effluents and the locations of outfalls have been documented for Oregon and Washington (Pacific Northwest River Basins Commission, 1973). The amounts of effluents were calculated on the basis of oxidizable organic material discharged but, because detailed composition of the effluents are unknown, interpretation about their impact on the aquatic environment must be limited primarily to effects on nutrients and dissolved oxygen.

Pockets of pollution occur in bays, inlets, and estuaries that have relatively high loads of waste. In some bays such as Coos Bay and Yaquina Bay, Oreg., oxygen levels fall to as low as 1-2 ppm in late summer when there is low inflow into the bays. Low dissolved oxygen and anoxic conditions in sediments have also been found during late summer in localized areas of Puget Sound and in Alaskan waters. Grays Harbor, Wash., has an intensified oxygen deficiency when deep water upwells and replaces the bay water during periods of low flow and high temperatures.

The lower Columbia River has had a special localized problem from periodic growths of slime. Wastes from pulp and paper production and from municipal sewage furnish nutrients that permit growth of *Sphaerotilus*, an organism between true bacteria and true fungi. The organisms combine with fiber, debris, and sand to form slime, which is aesthetically undesirable, coats fishing nets, annoys sport fishermen, and discourages water sports. There is no evidence that the slime is damaging to fish but its presence indicates that pollution problems exist. Occurrence of slime has decreased in recent years, concurrent with the discharge of less organic matter into the river.

The above conditions show that at times organic material has been added to some Northwest waters at rates faster than decomposition can occur. However, these obvious conditions do not furnish any clues about what materials are being added that may create more long lasting effects. A list of the principal known contaminants, their sources, physical characteristics, and reasons for concern from a biological standpoint are listed in Table 2.

Domestic Wastes

Both domestic and much of our industrial wastes are now processed in the same treatment plants. The composition of materials and the impact on the environment are different enough, however, that it is better to consider them separately. Communities and cities on the coasts of the Pacific Northwest and Alaska discharge both treated and untreated wastes into salt water. Reports on the present and projected waste loads have been published by the Pacific Northwest River Basins Commission (1973) and the Bonneville Power Administration (Bodhaine et al., 1965).

The principal problems from domestic waste water have been from bacteria, viruses, and organic material, but most of the bacteria and organic matter are now removed before discharge. Domestic wastes also contain significant chemical contaminants that enter treatment plants including petroleum oils, pesticides, herbicides, detergents, wastes from plastics, metals, and sometimes chlorine. Waste waters entering plants have been analyzed in more detail for both practical and technical reasons than the effluents, and few definitive statements can be made about either reactions or removal of the compounds during the treatment process. The effluents are monitored for characteristics such as coliform count, biological and/or chemical oxygen demand, total and volatile suspended solids, and phenols, in addition to total and ammonia nitrogen.

Widespread concern about what happens to sewage effluents in sea water is recent. Most work has been done with freshwater systems and the marine systems are less understood. The impact on marine systems and the materials that cause or do not cause problems must be defined before we spend time and money on treatment

Table 2.—Characteristics of contaminants discharged in coastal areas of the northeast Pacific.

Contaminants	Sources	Physical and Chemical characteristics	Biological aspects
Organic matter	Industrial effluents Sewage Land run-off Animals	Soluble, colloidal, particulate Causes turbidity Excessive amounts change character of bottom Excessive amounts cause anoxic conditions in water and sediments	Decomposition adds nutrients Decomposed by bacteria and fungi and thus undesirable growth often is increased Consumes oxygen Can concentrate other contaminants by adsorption Protects terrestrial bacteria and viruses in marine environment Can decrease light penetration and thus phytoplankton production
Synthetic organic compounds: Chlorinated hydrocarbons, herbicides, pesticides, polychlorinated biphenyls (PCB's), carbamates (Sevin), organic phosphates	Sewage and storm drains Industrial effluents Land Agricultural chemicals Atmosphere Sediments Ship repair, e.g., paint chipping Spraying: forests, fields, orchards, and urban gardens	Lipid soluble Slightly water soluble May be concentrated by oil slicks and by adsorption on particulates Transported in atmosphere Compounds can be synthesized to obtain specific chemical and physical characteristics. Thus, new compounds will continue to be developed. Decomposed by photolysis (light catalyzed)	Biological effects dependent on level of compounds, type of exposure, species, and environmental conditions including presence of other contaminants The greater the amount of chlorine in the molecule, the greater the toxicity, and the slower the degradation of the compound Stored in fat of animals Accumulate in food web Transported biologically by migratory species Compounds transformed by metabolism of animals Some species develop resistance Adversely affects reproduction and viability of young of many species Young more susceptible than adults Affects all trophic levels; often decreases food supply
Petroleum hydrocarbons	Oil spills Sewage and storm drains Industrial effluents Refinery waste Boats and ships Atmosphere Sediments	Varied, numerous compounds of many types Soluble, insoluble, volatile Altered by physical and chemical reactions, e.g., evaporation and photo-catalyzed oxidation Adsorbs on particles and settles in sediments Fresh oil, lighter than water, but partitions with volatiles evaporating, solubles dissolving, some floating	Decomposed by bacteria, action of animals not clarified Damaging to floating populations Effects of chemically altered compounds unknown Acute lethal toxicity by coating of gills and surfaces Sublethal problems unknown, polynuclear aromatics of greatest concern Paraffin hydrocarbons may have adverse effect on plants Food web accumulation unknown Can cause off-flavors in edible species Many species adapt to sublethal exposure Problems different for intertidal organisms, benthic organisms, finfish, and plankton
Metals	Natural levels Sewage Industrial effluents Mining (via rivers) Radionuclides Sediments Atmosphere	Solubility dependent on species, whether organic salt, organic complex, or organic compound Some airborne, e.g., lead Binds with organic matter in water and in sediments Reacts chemically with ions already in environments to change chemical form	Many metals are required nutrients Toxicity varies with chemical species; therefore, analyses and evaluation should be for amount in organic or inorganic form. Total amount gives little information Can accumulate in food web Transported biologically by migratory species Chemical species transformed by bacteria and animals Many biological species adapt to presence
Detergents	Domestic and industrial effluents	Soluble. Other characteristics depend on particular chemical compound Ionic and non-ionic forms Increase solubility of other contaminants, e.g., petroleum hydrocarbons	Toxicity varies with chemical compounds Synergistic effects with other contaminants, e.g., petroleum oil and detergent more toxic than either compound alone Causes frothing
Halogens Cyanids Ammonia	Sewage treatment Industrial effluents Animals Ammonia from nitrogen cycle (bacterial)	Chemical species determines solubility Chemical species related to pH Reacts with organic matter	Soluble forms often acutely toxic and lethal Problems worse in fresh water than salt water Diffusion and dilution important Irritants at sublethal levels
Sulfur compounds	Industrial effluents	Chemical species determines solubility Deposited in sediments	Compounds transformed by bacteria Hydrogen sulfide formed under anoxic conditions Hydrogen sulfide extremely lethal

(Continued on next page)

Table 2.—Continued.

Contaminants	Sources	Physical and chemical characteristics	Biological aspects
Heat: a) plume b) entrainment	Industrial cooling, including thermonuclear plants	Cooling system prior to return eliminates problem of temperature increase If not cooled, rapid diffusion important Effluent will contain other contaminants Increased temperature will increase solubility of other contaminants, and decrease oxygen levels	Permanent change in temperature will change flora and fauna Some species can adapt gradually and to a limited degree to temperature differences Heated effluents can be used for other purposes, e.g., aquaculture Synergistic effects with other contaminants Temperature changes can be critical in life processes of cold-blooded animals with effects on activity, oxygen consumption, feeding, reproduction, diseases
Change in flow of fresh water	Dams, flood control, stream diversions, fills, logging	Stratification of water column affects salinity	Salinity affects biota, estuarine conditions, marshes, river deltas Some species adapt to changes in salinity
Silt	Stream run-off Glacial debris Dredging Erosion	Turbidity Affects light and thus photosynthesis Transports other contaminants Settles and affects sediments Settles faster in salt water than in fresh water	If enough will clog gills and cause surface abrasions May change nutrients in water Other actions dependent on composition and other contaminants including amount of organic matter

systems that either may not do an adequate job or may do much more than is necessary.

Immediate toxicity is not a problem with effluents from domestic sewage. In fact, abundant marine life is usually found near discharge points where they feed on the nutrients furnished by the organic waste material. Potential problems are the longer term ones from accumulation of recalcitrant materials that degrade slowly, settling of organic materials that change the characteristics of organisms in the sediments, and introduction of toxic compounds, as well as introduction of bacteria or viruses that are pathogenic to humans or animals. The current state of our knowledge is such that we know so little about the processes that occur in marine waters that we cannot state with certainty which components may cause problems. Our knowledge, furthermore, is primarily about gross characteristics and the role of many trace components is still not clear.

Effluents

Effluent discharges from treatment plants are fresh water that contain variable kinds and amounts of materials. These can be roughly divided into soluble, floatable solids, colloids, and settleable materials. The dispersion and distribution of the soluble and colloid materials were discussed in the general section on contaminants.

The floatable, buoyant materials will rise to the surface where they become an aesthetic problem as well as cause turbidity in the upper layers and restrict light to phytoplankton with a possible effect on primary production. This problem is not serious in many estuarine areas because the amount of turbidity from this source is usually considerably less than the natural turbidity from rivers and land runoff. This is particularly true in the many areas where glacial streams are entering estuaries of the northeast Pacific Ocean. Oils and greases in the effluents will be in these floatables; thus the effluents may be a source of some of the oil slicks on the surfaces and beaches.

The denser effluents that settle near the vicinity of an outfall may influence the character of the sediments and the species of benthic organisms. This is again due to the organic material, and the rate at which these changes may occur is not clear. Pamatmat (1971) studied oxygen consumption of the seabed near a metropolitan discharge point about 3 years after the Municipality of Metropolitan Seattle started to discharge digested sewage sludge that contained oxidizable organic matter equivalent to about 0.3 percent biological demand. When oxygen consumption from sediments near the outfall were compared with consumption by sediments from other stations, no differences could be correlated with effects from settled sludge.

The total organic material added to the sediments also includes slowly degradable compounds. These include materials such as the chlorinated hydrocarbons and trace metals as well as other insoluble compounds that we do not now recognize as possibly detrimental to the marine environment.

The settling of organic materials to the sediments furnishes nutrients that permit abundant populations of benthic and epibenthic organisms. The condition of the demersal fish feeding in areas near outfalls is sometimes used to suggest whether problems are developing. Reports have been made on incidence of abnormalities and diseases of fish near sewage and industrial outfalls (Halstead, 1972; Southern California Coastal Water Research Project, 1973), but correlation with cause has two major difficulties. First, little is known about the incidence of abnormalities and disease in marine fish in uncontaminated areas. Second, many factors and interactions are occurring, and the cause and effect cannot be positively correlated in the state of our current knowledge. Nevertheless, studies and monitoring of the sediments and the animals living in and on these sediments offer the best clues available for detecting changes occurring in an area.

Bacteria and Viruses

Records from the past show that untreated sewage discharged into Northwest waters has resulted in polluted beaches and infected shellfish. Most sewage is now treated and the waters are cleaner in the 1970's than they were in the 1950's. The problem has not completely disappeared, however, because evidence exists that current treatment methods do not kill all the viruses and possibly not all the bacteria present in the wastes. The survival of terrestrial bacteria in marine waters is particularly important when the survivors are human pathogens and food organisms are infected. Baross and Liston (1968) isolated *Vibrio haemolyticus*, a human pathogen, from Puget Sound waters, sediments, and shellfish and found the greatest numbers near sewage outfalls during the summer.

The survival time of bacteria and viruses in seawater has been the subject of a number of studies with conflicting results and differing interpretations. Bernard (1970) reviewed work with *Escherichia coli*, which is used as an indicator bacterium for sewage pollution. Temperature is important, with a longer survival time at colder winter temperatures, but *E. coli* does not reproduce at the colder temperatures. The organic material present is important in survival and distribution of both viruses and bacteria. Viruses bury into organic particles, survive, are carried with the particles, and probably use them as nutrients. The bacteria may be taken up by filter feeders or adsorbed on particles. When they settle to the bottom some remain viable for several weeks. Thus, sediments, which do not have the random fluctuations of water samples, may be used to obtain information about the sanitation of an area.

Most of the work on contamination of an area from sewage has been done with *E. coli*, but this gives only a gross evaluation of the situation. The classic use of *E. coli* as an indicator organism is now recognized as inadequate for suggesting possible hazards. Specific organisms must be isolated, their survival times determined, and definition made of their potential hazard to marine organisms and to man.

Chlorine is the agent usually used to eliminate or reduce microbial organisms in sewage effluents. Free chlorine is highly reactive and may alter the compounds present in the effluent. Thus, chlorides, rather than chlorines, are often found in the effluent and their discharge apparently does not cause a problem in marine waters because of the ions already present. Reactions with organic material in the effluent, on the other hand, may chlorinate some of the compounds, which may then become more insoluble, less degradable, and may have increased toxicity. This field needs much more investigation. As a result of potential problems, other procedures for sterilization are being investigated, including the substitution of ozone as the sterilizing agent.

Industrial Wastes

Industrial effluents vary not only from one industry to another and among different plants within the same industry, but also from day to day in any one plant. For this reason as well as because effluents from many industrial plants now enter sewage treatment plants, this discussion will be based on some important waste materials that are being released into Northwest waters. The difficulty with this approach is that a number of factors must be considered before potential hazards from contaminants can be evaluated. These include the fate of the contaminant during treatment and after it reaches the water, both synergistic and antagonistic reactions with other contaminants, and the quality and movement of the receiving waters.

Despite these problems, discussion of total effluent would be more difficult—not only because of variability but also because although materials used in a plant can be listed, detailed knowledge of the composition of effluents is not available and is difficult to determine. The major potential effects that are hard to recognize are those from trace components, including those formed during processing, that may accumulate to levels dangerous to the biota. Northwest industries and known toxic or lethal materials that may be discharged are listed in Table 3. Industries located on major rivers that flow into salt water are included because of the importance to anadromous fish and because many of the contaminants will reach salt water. Most of the industries using salt water for disposal of wastes, other than wood products and food processing, are on Puget Sound and the lower Columbia River. Puget Sound still has water of

Table 3.—Sources of contaminants in Northwest waters.

Source	Important Products	Comments
Major organic wastes: Pulp and paper Domestic sewage Food processing	Chlorine Petroleum oil, greases Acids Sulfur compounds NH_3, amines Metals Detergents Biocides Organic polymers Bacteria, viruses	Formation of anaerobic conditions and hydrogen sulfide. Buildup of slowly degradable materials. Widely distributed. Point sources, concentrations highest at discharge point. Domestic sewage also nonpoint source from septic tanks, land runoff.
Major inorganic wastes: Chloralkali plants Aluminum Alloy metals Petroleum refineries and drilling Nuclear plants	Metals and minerals Arsenic compounds Fluorides Chromates Cyanides Biocides Temperature Sulfur compounds Detergents Chlorine Greases, oils Phenols and phenolic compounds	Mercury not discharged by chloralkali plants. Industrial-Puget Sound, lower Columbia River. Mining-southeastern Alaska Point Sources, concentrations highest at discharge point.
Minor importance or nonpoint sources: Farm animals Grain elevators Shipyards Woolen mills Paints Sawmill, plywood, hardwood industry Logging practices Sand and gravel Recreation areas Septic tank discharge	Pesticides Herbicides Fungicides Total organic wastes Detergents Petroleum products Solvents Silt	Point sources, controlled or of small volume. Nonpoint sources, small amounts and general distribution.

high quality except in some of the inlets and bays. We do not know, however, how much waste can continue to be discharged without significant environmental deterioration.

Many chemicals are applied generally in industrial plants during processing and cleanup. These include lubricating oils used with processing machinery, detergents used for cleanup, biocides of various types, acids and alkali for pH control, as well as chelating agents for scale prevention and heat. Possible compounds in waste effluents include literally hundreds of compounds. Reviews (McKee and Wolf, 1963; Battelle's, Columbus Laboratories, 1971; Becker and Thatcher, 1973) have been made on the known effects of many of these compounds with data on the lethal quantities. Holland et al. (1960) reported the toxic effects of a number of organic and inorganic compounds to young trout and salmon. Their data on lethal effects of effluents and chemical compounds include the differences between fresh- and saltwater environments, indicating the type of behavior induced in the fish at sublethal levels. MacPhee and Ruelle (1969) used young chinook, *O. tshawytscha*, and coho salmon in fresh water to test the lethal effects of 1,888 chemicals.

Wood Products and the Timber Industry

The use of water by the timber industry and the use of water for aquatic animals has a long history of more conflict than any other uses of water in the Northwest. The present trend toward additional pollution controls, decreased use of water, and minimized volume of effluents by the wood products industry means that the current period is one of transition and may result in fewer problems in the future. Examination of past history is of value from the standpoint of residuals still in the sediments, recovery of areas, and to suggest possible effects from proposed dredging of sediments containing residual effluent material.

Logging Logging practices are of interest primarily for two reasons: 1) the possible effect on spawning streams of anadromous fish; and 2) the effects from storage of logs in the water.

The clear cutting of logs practiced in the Northwest and the construction of logging roads have a major effect on erosion of the hillsides and on water runoff, hence the rate of flow of streams. The erosion has caused siltation in the streams and resulted in changing gravel spawning beds to mud bottoms. Current logging practices can and often do use methods to minimize the effects on streams by leaving a buffer strip between the logged hillside and the stream and by not logging hillsides that have a high potential for erosion problems. Nevertheless, this is still an issue and each area proposed for logging must be studied to determine logging methods necessary to minimize effects on streams.

The use of water to store logs has been said to cause deterioration. Phenols, lignins, and other materials dissolve whereas pieces of bark and wood chips collect in the sediments. The degree to which these cause problems has not been clarified.

Forest Products The forest products industry has been a major user of water in the Northwest both during processing and for disposal of waste. The industry manufactures pulp and paper, hardwood and softwood veneers, hardwood and softwood plywood, hardboard, and treated wood products such as railroad ties, poles and piling, and fence posts, as well as timber and lumber that are fire resistant, insecticidal, or fungicidal. Plants are located on both fresh and salt water and their effects on the biota have been studied for 40 years. The amount and composition of effluent from the plants vary not only in the different segments of the industry but also from plant to plant within each segment. Technology exists to eliminate or minimize the amounts of effluents and to detoxify all effluents before discharge. Plants manufacturing veneers, plywood, hardboard, and treated products minimize water use and are not discharging residual treated effluents directly into water.

Construction of new plants is expected to include methods to eliminate effluents. Although older plants may be granted interim variances for their disposal methods, they are expected to minimize effluents discharged into waters. The discharge of organic material is nearly eliminated by reuse of waste water or by chemical and/or biological oxidation. The principal problem with achieving the ideal zero elimination of discharged waste is that the amount of water used often precludes not returning some effluent. The pulp and paper industry has the biggest problem in controlling effluents. The industry has taken many steps in the last 20 years to decrease pollution effects. These have ranged from changes in processing to utilization of waste to detoxification of wastes. Recently a major processor announced plans to prepare pulp by a mechanical process. This method will result in a major reduction in the volume of water used and consequently will decrease the need to dispose of waste products in water. Other possible effects are unknown.

The pulp and paper industry has been a major source of pollutants that have affected marine biota of the Northwest. Most of the research on pollution from forest products has been on discharges from the sulfite and kraft mills. The literature contains conflicting results but enough work has been done that it is possible to draw some conclusions. A number of explanations can be made for conflicting information and some are worth mentioning because they apply to evaluation of other types of pollution. Two obvious reasons for discrepancies in results are that both effluents from different plants and conditions in the receiving waters vary for different plants. Another important reason is that all too often symptoms of a problem were observed and expensive treatments instituted, but major problems still existed, nevertheless, because the basic causes were not known and treatment of symptoms has not alleviated the problem. Parker and Sibert (1972) have shown, for example, that a major problem still existed from low levels of dissolved oxygen after reduction in the amount of organic matter from effluents of a pulp mill plant that were added to the upper fresh water layer of a stratified inlet (Alberni Inlet, British Columbia). The suggested cause was that the dark stain from the effluent blocked photosynthesis, affected the oxygen content even below the halocline, and played a major role in reducing the productivity at the freshwater-saltwater interface.

Sibert and Parker (1972) then developed a numerical model that was based on results from both laboratory chemostat studies and field observations. They concluded that effects from removal of organic matter did not penetrate the lower saltwater layer and thus had little effect on oxygen content below the halocline and that primary productivity in the upper layer was below normal until 90 percent of the stain was removed. This work did not include information about the effects on various trophic levels from removal of nutrients furnished by organic materials in the effluents.

The excellent work above was based on one aspect of the effects of pulp mill effluents—that on dissolved oxygen. A number of other aspects must be included in considerations about biological effects from the effluents. The untreated waste has a direct lethal toxicity for fish, but much of the components causing acute effects is removed along with the organic material during bacteriological treatment and oxidation of the effluent. The chlorine used to bleach pulp waste reacts with the organic material present and most of the chlorine is removed from the effluent before discharge. However, a potential problem exists in that some organic compounds in the effluent may be chlorinated and their toxicity increased. Servizi et al. (1968) investigated this with two compounds which could be formed from lignin during the pulping and bleaching process and found that chlorination did not increase their toxicity to fish but that the chlorinated compounds were degraded during treatment with activated sludge. Problems could result if there are chlorinated compounds that are not degraded because they may then accumulate in the food web if their ultimate disposal is in the marine environment.

The total composition of kraft or sulfite wastes has never been determined and both acute and subacute studies have usually been made on the effluents. A number of these studies, as well as avoidance studies, have been made on salmon, oysters, and organisms of the lower trophic levels that furnish food for fish. Since the effluents are now being treated before being discharged, this extensive literature will not be reviewed. Readers wishing to pursue this can start with the following references: McKernan et al., 1949; Williams et al., 1953; Alderdice and Brett, 1957; Gunter and McKee, 1960; Servizi et al., 1966; Parrish and Horton, 1971.

Untreated kraft mill waste has a number of toxic components. Neutralization of waste eliminates up to 75 percent of the toxicity. Volatile sulfides and mercaptans also contribute to lethal effects but these can be removed prior to discharge. The nonvolatile components also have significant toxicity, however. Leach and Thakore (1973) fractionated effluents from a kraft mill effluent resulting from pulping of 50 percent Douglas fir and 50 percent western hemlock and assayed the lethal levels on juvenile coho salmon. Resin acid soaps accounted for 82 percent of the toxicity of the nonvolatile constituents. The remaining toxicity was due to sodium salts of unsaturated fatty acids. A 10 percent reduction in fatty acid concentration eliminated their lethal effects. The variations in lethal levels for different kraft mill effluents probably is related to changes in the type and quantity of nonvolatile components, since these will vary depending on the raw material and processing methods.

Despite current trends toward decreased discharge of organic material from pulp and paper plants, large amounts have already been dumped in the waters and the question of what is happening in these areas is important. Servizi et al. (1969) made some interesting comparisons of toxicity to sockeye, *O. nerka*, and pink, *O. gorbuscha*, salmon from sediments from two areas. Sediments in one area were deposits primarily from sulfite pulp, board, and paper mills with a smaller contribution from sewage waste treatment. Sediments from a nearby area were deposits primarily from the silt load of a river. The polluted sediment had no benthic organisms such as crabs and worms. It had an oxygen demand of 6 ppm and contained gases such as hydrogen sulfide (H_2S), methane, and carbon dioxide. Samples of this sediment caused 100 percent mortality to sockeye smolts at concentrations of 1 percent sediment material. This level contained 2.3 ppm H_2S. At a level of 0.3 ppm H_2S no mortality occurred, but the fish were in distress as detected by coughing and frenzied swimming. Hydrogen sulfide was shown to be the primary problem but pulp fibers were noted to clog gills. The sediments of natural silt on the other hand contained small crabs and worms. It had a significant oxygen demand, two-thirds as much as that of the polluted sediment, but caused no mortality to fish within 24 hours at concentrations of 5 percent sediments.

The buildup of pulp waste was not as great in the above polluted sediment as it is in some sediments because the area had been dredged within the previous decade. The above study pinpoints the problems that pulp waste decays relatively slowly and that any decision to remove this type of waste material from sediments must be made cautiously.

Agriculture and Food Processing

Contaminants from agriculture and food processing may be both at a specific place, such as processing plants and grain elevators, or may be rather generally distributed, such as animal waste and land runoff of chemicals used in farming. The wastes from processing plants near urban areas are generally discharged into sewage systems and thus organic material is removed. Plants in more isolated areas are now being required to install methods to remove the organic material. Organic wastes from farm animals are more difficult to handle and problems have developed where there are concentrations of animals, such as in dairy herds and poultry farms. The agriculture industry uses large quantities of fertilizers, pesticides, herbicides, and fungicides. When these chemicals are properly applied large amounts will not get into the water, but even under favorable conditions some do wash into the waters via land runoff. Research is currently being conducted on the fate of many of these materials in soils to establish the conditions that determine what and how much of the compounds or their degradation products will enter the waterways. This information is essential to define potential problems in the aquatic environment from use of these materials.

The Chemical Industry

The chemical industry does not discharge large amounts of decomposable, oxygen demanding, organic wastes; components of the effluents, however, may be the types that are lethal and accumulate in the environment.

Aluminum Production The aluminum industry developed in Oregon and Washington following World War II because of cheap, abundant electric power and in turn became a reason to expand the power supply from the Columbia River. The industry also utilizes large amounts of water and has significant volumes of heated effluents. Ponds are often used to cool effluents and to remove the solids that settle. Cyanides and fluorides are present in effluents entering water. Welch et al. (1969) examined marine organisms near a diffuser from an aluminum plant on Puget Sound and reported that the number of species of invertebrate benthic fauna was lowest in the vicinity of the diffuser and increased with increasing distance north and south of the diffuser. This study was made too soon after the opening of the plant to make any comments concerning possible effects from accumulation of wastes.

Metals No iron ore is reduced to pig iron in this area but scrap is melted so that there are steel mills, ingot forgers, and foundries. Metals produced include ferrosilicon, ferromanganese, silicomanganese, and silicon. Components of effluents include acids, cyanide, and arsenic and chromic compounds, as well as oil and grease.

Chloralkali Plants Effluents from these plants were formerly a source of mercury in the aquatic environment, but the discharge of mercury and mercury compounds has been stopped. Levels of other discharged compounds are restricted and include chlorine (5.0 ppm maximum in effluent), alkali, phenols, and phenolic compounds.

Petroleum Refining and Drilling Petroleum refineries are of comparatively recent construction and consequently the quality and quantity of waste products are controlled. Effluents vary from plant to plant and from day to day in a single plant but components may be acids, alkalies, sulfides, phenols, ammonia, carbon disulfide, heat, and many others, in addition to oil and petroleum products. Refinery effluents, like most industrial effluents, can be treated so that they are not toxic to aquatic organisms. Underwater drilling is not permitted in Puget Sound, but it is occurring in Alaskan waters, including Cook Inlet. Environmental effects on marine organisms from this drilling are currently being studied. Environmental aspects of transportation of petroleum are discussed by Clark (1976).

Nuclear Plants Three possible sources of radionuclide contamination have occurred in the Northwest: atomic works, thermonuclear power plants, and experimental atomic blasts such as were tested at Amchitka Island in the Aleutian Islands. All of these sources have been monitored. The physical and biological distribution of radionuclides in the Columbia River, the estuary, and the adjacent ocean waters has been extensively covered by Pruter and Alverson (1972). The first reactor at Hanford went into operation in September 1944, and the amounts discharged have varied at different periods since then. Most of the materials discharged into the river are deposited in river sediments. The primary radionuclides discharged into the ocean are ^{65}Zn and ^{51}Cr. A number of pelagic and benthic fish and shellfish concentrate ^{65}Zn, but levels were not high enough to be of concern from the standpoint either of human health or of pathological conditions in the biota.

All contamination from thermonuclear power plants is not connected with radioactivity but also with production of heat and with chemicals used in the plant. Becker and Thatcher (1973) compiled a review of toxicity of nonradioactive chemicals actually or potentially associated with the operation and maintenance of nuclear power plants and cooling towers.

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