Effects on Environmental Stress on Fisheries Use and Enjoyment: A Historical Overview

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INTRODUCTION

Many stresses impact on fisheries use and enjoyment. They vary from disruption of habitat to the influence of pollution on the health of organisms and the viability of ecosystems. But stress in the context of this paper will be limited to the effects of chemical pollution, the main focus of interest in the Center's Environmental Conservation Division.

What is the legislative basis for our commitment to this important national issue? The National Marine Fisheries Service is responsible for providing data for the conservation and management of fisheries stocks of the United States Continental Shelf. In this capacity, it rightly plays a key role in investigating actual and potential impacts of pollution on these stocks and the ecosystems on which they depend.

Moreover, Congress has recognized the responsibilities of the National Marine Fisheries Service and its predecessor agencies in the conservation and management of living marine resources through a series of legislative mandates. The National Ocean Pollution Research, Development, and Monitoring and Planning Act of 1978 specifically names the National Oceanic and Atmospheric Administration (NOAA) as the leading Federal agency to plan and coordinate ocean pollution monitoring and research: Section 202 of the Marine Protection, Research, and Sanctuaries Act of 1972 directs the Department of Commerce to "initiate a comprehensive and continuing program of research with respect to the possible long-range effects of pollution, overfishing, and man-induced changes in ocean ecosystems." The Magnuson Fishery Conservation and Management Act of 1976 requires the Secretary of Commerce "to initiate a comprehensive program of fishery research, including the impact of pollution...on the abundance and availability of fishery resources."

Until recently, the impact of pollution on marine organisms was addressed primarily after environmental catastrophies had occurred. Yet, lacking adequate information on how toxic chemicals altered living marine systems, it was often impossible to identify, much less quantify, the acute effects of even a massive spill of hazardous material. Even more lacking was information on long-term effects from major spills or from the gradual degradation of the environment from continuous, low-level estuarine and marine pollution (Malins 1980). I

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believe that steady progress has been made in the last decade in coming to grips with important issues relating to the short- and long-term impact of pollution on fisheries. However, a number of questions still remain unanswered.

HISTORY

In the Pacific Northwest, a small amount of research was conducted prior to 1970 by Federal agencies on the effects of chemical pollutants on marine organisms. In the spring of 1970, responding to an upsurge of interest in man's impact on oceans, research on the effects of pollution on marine life was initiated at this Center. What then have we learned from this research in the last decade or so?

Using highly sophisticated analytical techniques, many of which were developed in coastal and estuarine environments, such as the New York Bight and Puget Sound (Malins et al. 1980b), we were able to learn where many of these compounds accumulate and, to some extent, how they may adversely affect marine life. But it is only in the last few years that we have begun to really appreciate the immensity and complexity of the problem revealed by these new, highly sensitive techniques.

There are in fact an estimated 63,000 chemicals in common use. The registry of the American Chemical Society contains over 4 million entries and is growing by 6,000 chemicals each week. Many of these chemicals, produced to satisfy technological and economic needs, eventually find their way into the marine environment (Malins 1980). It is estimated, for example, that 4 million metric tons of petroleum enter our oceans each year. Because of threats like this it is necessary to continually expand our understanding of the effects of pollutants on marine organisms. Failure to do so many well adversely affect the viability of our fishery resources and our use and enjoyment of them.

Now, let me mention some important facts about the pollutants themselves. Chemicals such as polychlorinated biphenyls (PCBs) enter marine environments and remain there for long periods of time, partly because of their resistance to chemical and biological changes. We can analyze for many, but by no means all, of these persistent chemicals. Many of these chemicals tend to bind to suspended particles that eventually end up in bottom sediments where important benthic species, such as flatfish reside. Other compounds such as hydrocarbons from fossil fuels are readily transformed in the marine environment through chemical and biological processes into a host of "new" chemicals. Most of these "new" chemicals cannot presently be detected in marine samples, even with our sophisticated analytical techniques (Malins et al. 1980a, Malins and Hodgins 1981).

Despite these problems, however, we are successfully identifying pollutants in marine environments and relating their presence to alterations in the health of important fishery resources.

How do we pursue this type of research? In the Environmental Conservation Division, we take an interdisciplinary approach because this is critical to obtaining a credible perspective of marine pollution. Our research teams are made up of highly trained specialists in areas such as analytical chemistry, biochemistry, clinical chemistry, ecology, pathology, electron microscopy, immunology, and behavioral biology. Our scientists and technicians work together in a concerted way, applying their particular expertise to the solution of complex problems.

Actually, one of our major concerns is whether pollutants present in marine environments are available to organisms. Many pollutants are found in seawater, but they are not all taken up by marine life to the same extent. For example, PCBs tend to accumulate in fish to a greater degree than do certain metals, such as cadmium. Fish can concentrate water-borne PCBs in their bodies several hundred thousand times the concentrations in seawater; however, cadmium is often concentrated only a few hundredfold at most.

From the point of view of protecting our fishery resources, perhaps the most important question is "Are pollutants affecting the health of marine organisms?" To answer this question we need to know which pollutants organisms are exposed to in the marine environment, which ones they tend to accumulate, what happens to the pollutants inside the animals, and what are the accompanying biological changes are (Malins 1980). With this evidence in hand, balanced and meaningful judgments are possible.

You may wonder how our scientists attack such a multifaceted problem. To begin with, analytical chemists have a firstline responsibility in the interdisciplinary approach. It is their job to find ways to detect and quantify pollutants in seawater, sediments, and organisms. These pollutants, frequently occurring at parts-per-billion or less, have to be analyzed against a background of complex mixtures of hundreds of "natural" compounds. The chemists have a formidable task, and their imagination and ingenuity is constantly challenged as they attempt to distinguish between myriad synthetic chemicals and "natural" substances in the multifactorial world of oceans and estuaries (Malins et al. 1980a, Malins 1981).

CURRENT RESEARCH

The Center's analytical capability resides in NOAA's National Analytical Facility, which was founded in 1976 as part of the Environmental Conservation Division. It is here that analytical chemists and technicians are involved in assessing pollution in coastal waters and estuaries of the United States. They also provide "analytical backup" for laboratory and field studies conducted by other Division scientists and technicians concerned with the fate and effects of pollutants on marine life. The facility utilizes state-of-the-art techniques, such as gas chromatography coupled with mass spectrometry and advanced data processing. Our analytical capabilities match or exceed those found anywhere else in the world. The staff is strongly committed to the development of new techniques; they are constantly alert for new ways of analyzing marine pollutants. Their research has resulted in new procedures for the routine analysis of environmental samples, and their techniques are continually modified to meet changing needs. Analytical methods developed here at the Center are being used in laboratories throughout the world, and we serve as a focal point for intercalibration studies.

The analytical chemists work closely with highly qualified biochemists, pathologists, and other specialists within the Division, as I have indicated. Data on the types and concentrations of pollutants in marine samples are of great importance to our biological scientists, helping them to broaden their understanding of marine pollution--that is, how it may affect the health of important resource species. In a reciprocal way, information from biochemical studies on what happens to pollutants and their metabolites in organisms is helpful to the analytical chemists. It tells them what to look for in organisms exposed to pollutants in the laboratory or field and guides them in research on new methods.

Let me illustrate how the team approach works in practice. In laboratory studies with marine organisms, our biochemists showed that aromatic hydrocarbons labelled with radioactivity are converted to metabolites, some of which are toxic (Varanasi and Gmur 1981). The findings of our biochemists have had a major impact on the scientific community and on those concerned with the fate of chemicals in marine life. Responding to the advances made by our biochemists, our analytical chemists developed methods to analyze for the conversion products in environmental samples (Krahn et al. 1980,1981). Moreover, with immediate access to the latest biochemical findings, our pathologists were able to use this information in attempting to understand the causes of pathological lesions, such as liver tumors in English sole living on heavily polluted sediments in Puget Sound (McCain et al. 1977). Thus, the team approach maximized the acquisition of data obtained on the nature of pollution and its effects on marine organisms.

How are our laboratory and field studies conducted? In the laboratory, experimental conditions relating to how pollutants bring about biological change can be controlled; in the real world of oceans and estuaries, however (where influencing factors are immensely complex), prevailing conditions are usually very difficult to evaluate and control. Thus, laboratory studies are often the only reliable means of obtaining critical information--that is, information that helps us broaden our perspective and increase our understanding of cause-and-effect relationships between pollutants and alterations in the health of organisms.

As an example, in one laboratory study flatfish were exposed for up to 4 months to sediment containing petroleum hydrocarbons. We determined through routine chemical analyses that the flatfish accumulated very few of the hydrocarbons present in the sediment (Figure 1), (McCain et al. 1978, McCain and Malins in press). In a related experiment in which flatfish were exposed to a specific hydrocarbon containing a radioactive label, we followed the hydrocarbon's fate in the fish's body (Varanasi and Gmur 1981). We found that the fish converted the hydrocarbon into a variety of metabolites that remained in the tissues for a long time. Thus, we concluded that flatfish exposed to petroleum in sediments build up metabolic products from hydrocarbons, rather than store the hydrocarbons unaltered (Varanasi and Gmur 1981). These metabolites, some of which are thought to be more toxic than the hydrocarbons themselves, and which escape the analytical chemist's eye, must now be taken into account in making judgments about the effects of hydrocarbons on marine life.

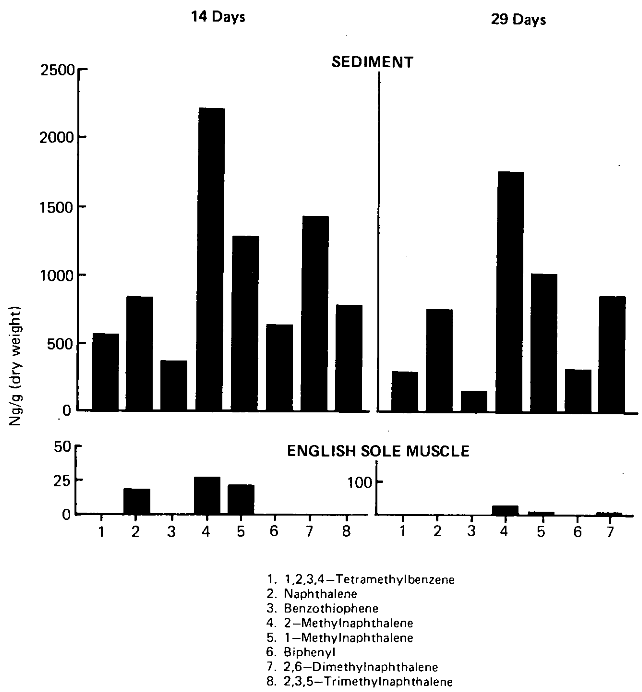

Figure 1
Concentrations of major aromatic hydrocarbons in Prudhoe Bay crude oil (PBCO) contaminated sediments and in the English sole associated with the sediments at 14 and 29 days. Tissue levels are an average of two replicated analyses of 10 g muscle samples from two fish. Control fish tissue did not have detectable levels of PAH.

In this same study, significant biological changes were observed. The petroleum-exposed flatfish had unusually high accumulations of fat in their livers and also showed changes in blood chemistry. They also lost weight and had higher mortalities than unexposed fish (McCain et al. 1978). Thus, by looking into this problem from several directions, we learned how sediment-bound hydrocarbons are "processed" by flatfish into potentially toxic chemicals we cannot routinely detect, and we further identified related and potentially serious biological changes. In fact, the information was extremely useful in planning and understanding field studies and also contributed in a major way to a number of important local and national decisions relating to environmental impacts.

What are some important conclusions from our laboratory studies? It has become apparent that early developmental stages of aquatic species are particularly susceptible to damage from trace amounts of pollutants (Malins and Hodgins 1981). We have, therefore, increasingly focused our studies on effects of pollutants on reproduction and early developmental stages of fish and invertebrates.

Again, to give a specific example, in one experiment we fed high doses of Alaskan crude oil (1000 ppm added in food) to maturing rainbow trout (Hodgins et al. 1977). We started the feeding of the oiled food 7 months before they were due to spawn and continued the feeding through spawning and beyond. Control fish were fed the same diet except that it did not contain the oil. The oiled food was well accepted by the trout. We evaluated mortality of the adults and hatching success of the offspring. Results indicated there was no detected oil-caused mortality during the study, and surviving fish were mostly fat, normal appearing, and vigorous--even after a year on the oiled food. Moreover, there was no significant effect on either egg viability or sperm viability as evaluated by hatching success. The conclusions were that oil fed to the parents had no demonstrable effect on their survival and no effect on subsequent hatching success of offspring.

But there is another side to the coin. Our studies of effects of petroleum on hatching and normal development of a species of flatfish and surf smelt provided quite different results. In these studies the parents were not exposed to the oil, but the fertilized eggs (embryos) were. That is, the oil was in the water in which the eggs were incubating. Results of the flatfish studies demonstrated that parts-per-billion concentrations of oil can cause mortalities and abnormal changes in flatfish larvae and prevent the development of embryos (Figure 2 and 3). These effects occurred at doses well within the range of concentrations that could occur following an oil spill.

Similar, but not as severe, effects were noted in surf smelt after oil exposure of embryos and larvae (Hawkes and Stehr in press). In addition to the mortality and grossly abnormal development found in a flatfish, damage at the ultrastructural level was noted in surf smelt retinas and brain tissue.

Overall conclusions from these studies on reproduction and hatching success are that: 1) under some conditions and with some fish species oil exposure does cause damage and 2) under other conditions and with other species there is either no evidence of damage, or different patterns of abnormalities occur.

Turning to another subject, we have also participated in field studies relating marine pollution to altered health of organisms. The grounding of the tanker Amoco Cadiz off the coast of France in 1978 was an opportunity to apply techniques we have developed to a real world situation--a massive oil spill. In collaborative efforts between our scientists and other scientists within NOAA, mussels were placed in cages 1 m below the water surface off the coast of France, either directly in the path or away from the path of the oil spill, to determine how the oil might affect their health (Wolfe et al. 1981). Our microscopists found that mussels from the spill zone or in the path of the spill showed abnormalities in their cellular structure, whereas mussels from a reference or "clean" site appeared normal.

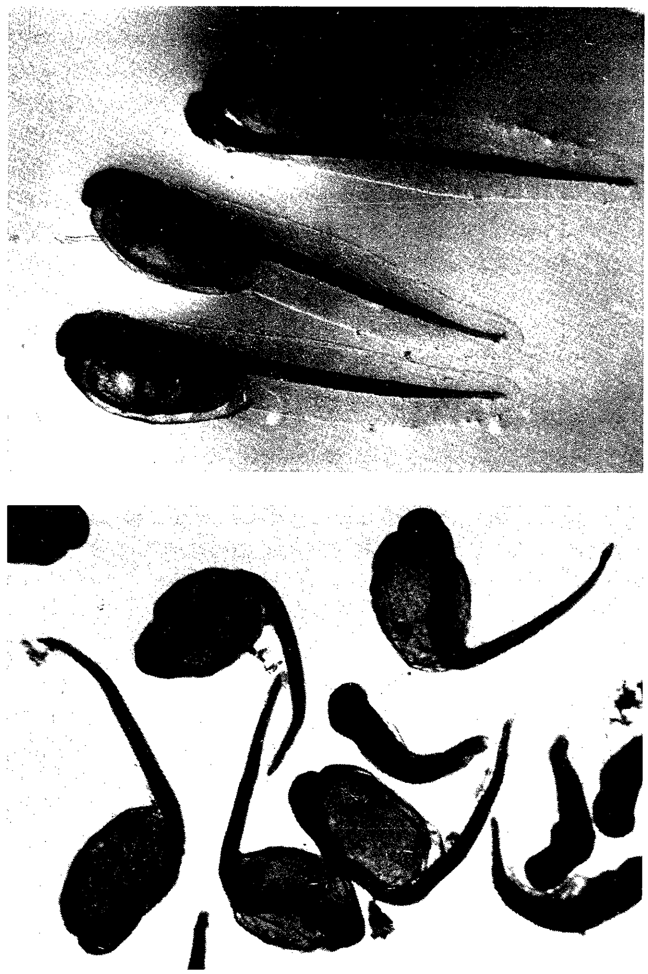

Figure 2
Sand sole *(Psettichthys melanostictus)* eggs exposed to Prudhoe Bay crude oil produced larvae with severe scoliosis. Upper photo, control sand sole larvae; lower photo, eggs incubated for 7 days in a system containing the saltwater-soluble fraction of Prudhoe Bay crude oil resulted in 66% abnormal larvae. Initial concentration of 527 parts per billion (ppb) was decreased to 64 ppb. Embryos were prematurely aborted and larvae hatched with severe scoliosis.

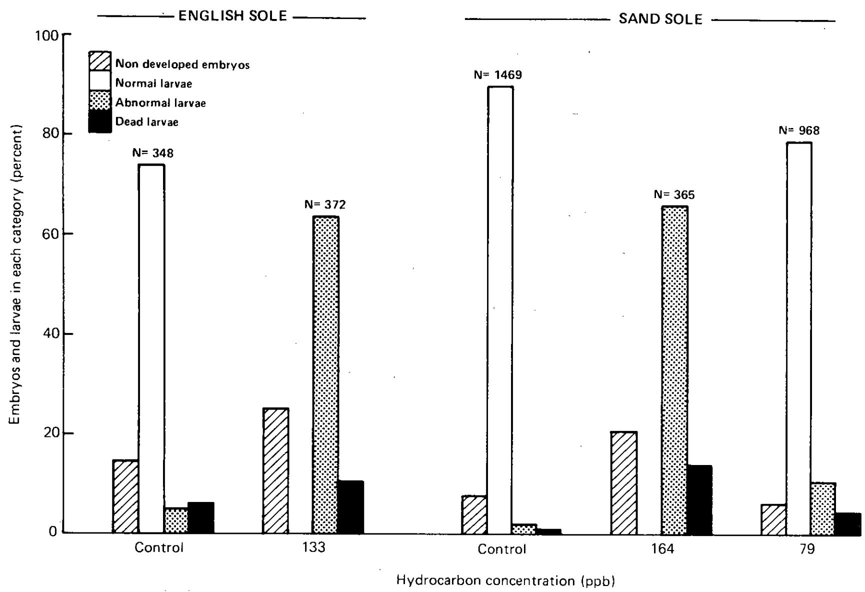

Figure 3
Mortalities and abnormalities in English sole and sand sole embryos and larvae exposed to various hydrocarbon concentrations of the seawater-accommodated fraction of Prudhoe Bay crude oil. Data were collected at the time of hatching (end of an 8-day exposure).

Our chemists found petroleum contamination in the mussels exposed directly in the path of the spill. Using high performance liquid chromatography, they also found evidence of contamination from non-hydrocarbon products of petroleum. In fact a major breakthrough was obtained when they demonstrated for the first time that the products of hydrocarbon conversions I mentioned earlier were particularly associated with mussels obtained from the impact zone.

Thus, employing an interdisciplinary approach, we were able to gather two types of important evidence relating the presence of oil from the Amoco Cadiz to altered health of shellfish. We have studied in similar ways the impacts on marine life of other oil spills, such as the Argo Merchant off Nantucket (MacLeod et al. 1978) and the General M. C. Meigs off the Washington coast (Clark et al. 1978).

We have studied relations between chemicals and disease in marine life closer to home, i.e., Puget Sound. It is important to mention, however, that the presence of trace amounts of toxic chemicals in marine life does not imply, per se, a threat to either the organism or the consumer. Only carefully conducted studies, considering many interrelated factors, can establish whether a significant risk really exists. Revelations of traces of known toxic chemicals in the environment are sometimes misinterpreted by the unskilled or unknowledgeable to spell disaster when, in fact, no significant danger can be established or predicted on the basis of scientific evidence.

To return to the issue of Puget Sound--beginning in 1978 and continuing through the spring of 1981, samples of sediments and selected bottom-dwelling fish and invertebrates were collected from urban embayments, i.e., near industrialized areas, and from nonurban (reference) stations in Puget Sound and adjacent waters. The study was a cooperative effort with NOAA's Marine Ecosystems Analysis (MESA) Puget Sound Program (Malins et al. 1980b).

Our chemists analyzed sediments and tissues for a large number of organic and inorganic chemicals, including aromatic hydrocarbons, PCBs, chlorinated pesticides, other chlorinated organic compounds, and metals. In most cases, the same animals from which tissues were taken for chemical analyses were also examined by our pathologists for grossly visible and microscopic abnormalities. In addition, the community characteristics, such as abundance and species diversity, of invertebrates and fish living in contact with sediment were defined by our biologists.

Aromatic hydrocarbons, PCBs, and chlorinated butadienes were widely distributed in Puget Sound sediments; however, the concentrations varied extensively both among and within embayments. The sediments in embayments adjacent to the most populated areas, Elliott Bay (Seattle) and Commencement Bay (Tacoma), contained the highest concentrations of aromatic hydrocarbons and PCBs; chlorinated butadienes were highest in Commencement Bay where industries that manufacture chlorinated products are located. Table 1 presents comparisons of the concentrations of compounds representative of the three classes of chemicals in sediments from these two bays with concentrations in sediment from Case Inlet (a reference area in Puget Sound) and in sediment from the New York Bight.

As an example of the complexity of the mixtures of chemicals in sediments, more than 500 aromatic hydrocarbons, appearing to be mostly derived from fossil fuels and the combustion of fossil fuels, were revealed in one sample from the Hylebos Waterway in

Table 1
Concentrations [μg/g (ppm) dry weight] of selected pollutants in sediment from various locations in Puget Sound and the New York Bight.1/

Pollutant	Puget Sound: Duwamish Waterway (6 samples)	Puget Sound: Hylegos Waterway (5 samples)	Puget Sound: Case Inlet2/ (2 samples)	New York Bight: Christensen Basin3/ (3 samples)
	ug/g (ppm) dry weight			
1- to 5-ring aromatic hydrocarbons	11	16	0.3	5.4
Benzo[a]pyrene	0.6	0.5	0.02	0.2
Benz[a]anthracene	1.1	1.2	0.02	1.0
Polychlorinated biphenyls	0.3	0.5	0.002	1.1
Chlorinated butadienes	0.02	0.4	0.007	ND4/
Hexachlorobenzene	0.0002	0.03	0.00003	0.005

1/ Analyses by National Analytical Facility, Northwest and Alaska Fisheries Center, Seattle.
2/ A reference site.
3/ Located near the mouth of the Hudson River.
4/ ND = not detected.

Tacoma. Scores of chlorinted compounds, in addition to PCBs and hexachlorobenzene (HCB), were associated with certain embayments. This was especially evident for sediments collected near Tacoma, Port Angeles, Bellingham, and Everett.

To briefly touch on the toxic metals in sediment, arsenic and mercury were detected only in sediment from urban areas, whereas lead was found in both urban and nonurban areas.

Sediment-dwelling worms, clams, shrimp, and crabs from urban embayments contained levels of aromatic hydrocarbons that were higher than levels detected in these animals from nonurban areas. The aromatic hydrocarbons in fish livers from all areas were generally low. As you can guess by now, these compounds were subjected to extensive metabolism and were replaced, in effect, by potentially toxic metabolites we cannot detect at present. Concentrations of PCBs and other chlorinated compounds were generally higher in organisms from urban than from nonurban area.

We have studied the chemicals in sportsfish, such as salmon and cod. I am pleased to report that concentrations of chlorinated compounds and hydrocarbons in edible tissue (muscle) were very low in these fish from both urban and nonurban areas. Concentrations of PCBs in livers of salmon from both types of areas were also low. In sharp contrast, concentrations of PCBs in the livers of English sole caught from urban areas were as much as 15 times higher than those from nonurban areas.

Muscle of English sole, Pacific cod, and salmon from both urban and nonurban areas contained low concentrations of lead and mercury. Arsenic was found in sole muscle from both urban (Duwamish and Hylebos Waterways) and nonurban (Port Susan) areas, and in cod and salmon muscle from Elliott Bay, Commencement Bay, and Point Jefferson.

Bottom fish, crabs, and shrimp had a variety of pathological conditions. The most commonly observed lesions were either associated with infectious agents, or they were caused by unknown factors. Some of the lesions of unknown cause were found only, or were most prevalent, in fish from the urban embayments. In English sole, the fish species most widely distributed throughout Puget Sound, these urban-associated lesions included liver tumors, and "preneoplastic" and necrotic liver lesions. In some cases, the liver neoplasms were grossly visible as nodular discolorations on the liver surface (Figure 4).

Figure 4
English sole liver containing multiple neoplastic nodules.

Fish with the above-mentioned lesions, as well as other types of lesions, had abnormal changes in blood cell counts and in the concentrations of serum

Table 2
Pathological conditions in English sole from the Duwamish River, a polluted estuary in Seattle, Washington, as compared to English sole from McAllister Creek, a reference ("clean") estuary 80 miles south of Seattle.

Abnormalities in English sole	Duwamish River		McAllister Creek	
	Number of fish examined	Frequency of abnormality (%)	Number of fish examined	Frequency of abnormality (%)
Liver tumors				
Adults only (1975)[1/]	62	32	37	0
Adult and juvenile (1978)[2/]	252	8	18	0
Fin erosion[2/]	476	2	71	0
Severe hepatocellular lipid accumulation[2/]	256	45	37	11
Gill hyperplasia[2/]	256	15	37	0

1/ McCain, B.B., et al. (1977)
2/ Malins, D.C. (1980)

components. Some of these changes were indicative of severe organ dysfunction. English sole with liver neoplasms and "preneoplastic" lesions were most prevalent in Seattle's Duwamish Waterway and in Tacoma's Waterways. In the Duwamish Waterway, the prevalence of adult sole with liver neoplasms was found to be as high as 32% (20 of 62 fish) in a study conducted in 1975. More recent studies involving both juvenile and adult sole have found a liver neoplasm prevalence of 8% (20 of 252 fish, Table 2). No sole with liver neoplasms were found in nonurban reference areas.

What can be said about a possible link between the toxic chemicals and the observed diseases? We employed statistical methods to evaluate possible relationships between the prevalence of English sole with liver lesions and the chemical composition of the sediment in areas from which the affected fish were captured. In one method, the sampling stations were arranged into eight groups on the basis of statistical considerations. The highest prevalences of English sole with these lesions were found at stations in two groups. These groups were characterized as having high concentrations of sediment-associated metals and aromatic hydrocarbons. This apparent association between the prevalence of these liver lesions and the sediment concentrations of the two classes of chemicals was supported by the results of another statistical test. The prevalence of English sole with liver tumors and certain other lesions was positively correlated with the relative sediment concentrations of aromatic hydrocarbons and metals, whereas the prevalence of the species with "preneoplastic lesions" was positively correlated only with aromatic hydrocarbons. However, it should be mentioned that English sole are mobile, which must be borne in mind in evaluating the data.

In Puget Sound, urban-associated lesions in shrimp and crabs were limited to necrotic lesions of the gills. Affected shrimp were most prevalent in the Hylebos Waterway, in the upper portion of the Duwamish

Waterway, and in Sinclair Inlet. Crabs with gill necrosis and related abnormalities were most prevalent in the Duwamish Waterway.

The abundance of fish, and the number of fish species, were generally higher in the estuarine bays (Commencement and Elliott Bays) compared to the inlets and open bays. For sediment-dwelling invertebrates, the average highest species richness values were found in the reference areas, e.g., Port Madison, and the outer portions of the estuarine bays, e.g., West Point. The lowest values were in sediments from the urban waterways, e.g., Hylebos Waterway, and inner portions of the urban associated areas, e.g., Budd Inlet. Thus, it appears that disruptions of community composition or structure are related to the stresses of pollution in the industrial areas.

The findings indicated that hundreds of chemicals are present in Puget Sound sediments in trace amounts from as far north as Bellingham Bay to as far south as Budd Inlet (near Olympia). Many of the chemicals are also found in a variety of benthic and pelagic organisms; the question of the threat they pose to these organisms or to the human consumer is not known at present and con only be determined through further research.

Efforts to keep track of pollution in Puget Sound and understand its effects on the resource and the consumer of fishery products will require the following approaches:

> The identification of types and concentrations of chemicals, emphasizing accumulations in important marine organisms; the identification of chemicals responsible for altering the health of Puget Sound marine life; the evaluation of the health of marine life through laboratory studies and by monitoring chemical accumulations and biological changes in so-called "indicator" organisms placed in enclosures around Puget Sound; studies of risk assessments to evaluate possible threats to human health; and the establishment of procedures for coordination of activities and dissemination of information among agencies responsible for protecting marine life and human health.

Some of the problems we face in studying the effects of pollution on marine environments have been described, together with selected examples of our findings. Some of our efforts have directly influenced decisions relating to the effects, or potential effects, of pollution on fisheries and their enjoyment. We have provided data and testified at an Adjudicatory Hearing for NOAA on a proposed refinery at Eastport, Maine (Pittston Co.); presented testimony on the Disposal of Dredge Spoil from New York Harbor at the Hearing of the Committeee on Merchant Marine and Fisheries, U.S. House of Representatives; contributed data to and participated in preparation of a synthesis document for the Bureau of Land Management on impacts of petroleum on proposed oil and gas lease areas of Alaska, e.g., Norton Sound and St. George Basin; presented data and testified at the Washington State Energy Facilities Site Evaluation Council Hearing on the proposed Northern Tier Pipeline and contributed to the position of the National Marine Fisheries Service to deny the application; and provided data and advised state and local agencies on continuing problems of chemical pollution in Puget Sound.

CONCLUSION

Overall, it can be argued that the only rational way to protect our fishery resources from the adverse impacts of human activities is through increased understanding and the development of national positions and actions based on that understanding. In all of our efforts in the Environmental Conservation Division, we have been, and will continue to be, acutely conscious of the role we play--which is the acquisition and scientific interpretation of credible data that contribute to balanced administrative decisions on the use and enjoyment of our nation's fishery resources.

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