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Our Threatened Oceans

Introduction

My title, "Our Threatened Oceans", may sound both ominous and pessimistic. While the subject is ominous, it need not cause pessimism. Although the list of threats and pressures we exert on our oceans and its resources might inspire despair, we must overcome such emotions and rationally approach these threats with sound science. This means using the best scientific means possible to determine which of the threats are real and which perceived, what is the magnitude of the impact of each particular threat, and how we can best mitigate the impacts of these threats. In addition to science, we also need to consider social and economic factors in our solutions. I strongly believe that if we proceed logically and rapidly the public will accept the hard scientific facts, especially if proper solutions are offered with documentation of prominent threats and their effects. Providing solutions as well as documentation is particularly important in the field of pollution, about which I have some knowledge. I truly feel we have no choice but to accept this challenge if we wish to preserve what remains of our resources and ecosystems.

The research described herein is based on the collective efforts of the scientists of the Northwest Fisheries Science Center. I gratefully acknowledge their dedication to using an interdisciplinary team approach to solve marine pollution problems. In addition, I thank Ms. Cyd Pompel for her editorial assistance and typing of this manuscript, and Mr. Tom Hom for preparing the visual presentation that accompanied my speech and the graphics in this manuscript.

Critical Habitat in Jeopardy: Conditions in the United States

The term "ocean" can be used rather broadly to include coastal, estuarine, and riverine systems. This is indeed a more complete description because many of the important and valuable ocean-going fish species spend critical phases of their life cycles in rivers and estuaries. For example, salmon spend the beginning and the end of their lives in rivers, often crossing urban estuaries and coastal areas *en route* to and from open ocean. In some coastal areas, as much as half of the fisheries are dependent on estuaries for their survival. Unfortunately, these estuaries, which are so critical for fisheries, often suffer from the adverse effects of anthropogenic activities related to urban growth and development. In the northwest United States, hydropower systems, logging, waste discharge, waterway development, and mining are some of the activities that have destroyed or altered critical habitat. One result of this is the decline of many salmon and groundfish stocks. In the southwest, especially in California, water diversion causes change in salinity in estuaries and lower water flows for salmon to pass through. In Alaska, an area we think of as pristine, many of the fisheries are being affected by outer continental shelf development, and timber harvesting.

In an area closer to home for Halifax, the northeast United States suffers from coastal habitat modification, contaminant and nutrient loading, ocean waste disposal, water diversion, and marine debris, all of which could be contributing to the severe depression of fish stocks. The activities listed for each of these regions are good examples of conflicting use of land and water resources. While we know full well that we will not, and we should not, turn off power, stop operating dams or stop developing waterways, we need to develop better scientific information that can help us make wise decisions regarding the balance of such activities with resource protection.

Other Major Threats to Marine Resources

Overfishing

Habitat degradation is one of the many threats that we exert on our marine resources. Another prominent threat is overfishing. The impact of overfishing is obvious and in recent years over-exploitation of stocks, combined with severe environmental conditions, has resulted in precipitous declines in many stocks of fisheries on both the Atlantic and Pacific Coasts. Large scale fisheries not only affect targeted and desirable stocks that may be overfished, but also may result in discards of other species caught incidentally, particularly females and juveniles which are needed to maintain stocks. It is believed by some that one remedy to overfishing is to halt or severely regulate fishing, but this is both impractical and not based on rational, scientific facts. We need to develop an understanding of the threshold where fishing becomes overfishing. In addition, we must develop techniques to minimize by-catch, or discards, and utilize all the species that are caught in order to avoid waste and most efficiently meet the demand for fishery products. Research on these and other fishery management issues is under way, and various measures are being implemented to regulate U.S. fisheries, both in terms of harvest allocation and by-catch.

Introduction of Foreign or "Exotic" Species

In recent years, the threats to our ecosystems have also included introduction of "exotic" species. Increased long-range transport and transfer of goods and people from around the globe not only bring desired guests and goods to our shores, but also many undesired and unexpected creatures, ranging from bacteria and viruses to sea creatures that travel from one coast to another in the ballast waters of ships. Proliferation of zebra mussels in the Great Lakes is one example of how an alien species can flourish in an ecosystem after introduction. We must also consider the impact of intentional introduction of desired species when such an introduction becomes overwhelming and can devastate wild populations. Introduction of hatchery fish—salmon, for example—is a much needed and well intended augmentation of declining stocks. However, large-scale introduction of these fish can crowd the migration corridors, causing a potential decline of wild stocks and thus reducing genetic diversity and robustness. Any introduction, well intended or inadvertent, can affect the fragile balance of aquatic ecosystems.

Ultraviolet Radiation

Another threat that is not well understood right now but is the subject of much study is the threat of increased UV radiation. The UV radiation can have dire consequences for critical life stages, such as eggs and larvae of many organisms, that are spent in surface or boundary layers between air and water or land and water (beaches). What is needed to address these issues is high quality data and documentation, and then solutions based on the science. The overall objective is to develop basic scientific information on the effects of human's activities on valuable marine organisms and their habitats. This information can then be used to produce real-time solutions to conserve these resources through decisions made on projects, permits, leases, licenses, programs, and policies affecting the waters of the United States, Canada, and the world.

What Role Does Pollution Play?

If we try to gauge the relative impact of the threats described above, especially in terms of sheer numbers or magnitude, pollution may not be the largest threat. For example, overfishing and physical degradation of habitats may have a much bigger effect, partly because we can see the resulting devastation or enormity of these activities. Pollution, except for oil spills and marine debris, is not visible and generally does not cause mass mortality. The impact of pollution is more insidious and chronic effects manifest themselves many years later. The question that is frequently asked of me is "Why are we so fascinated by pollution effects, whether real or perceived?" Our fascination stems from the fact that pollution, unlike other threats, has both direct and indirect effects on us.

The Dual Effect of Pollution

Pollution touches us indirectly by affecting the health and survival of our resources, posing both ecological and economic risks. In addition, because contaminants can accumulate in our foods, we can be directly affected. The fact that chemicals that cause a variety of ill effects on sea creatures can, in the same way, affect our health has riveted our nation's and the world's attention to "war stories" on pollution. Unfortunately, while pollution stories get much attention in the media, we have not made much progress in addressing the issue scientifically and logically. I don't mean that we don't spend a great deal of effort studying pollution effects. Rather, I feel we do not often approach the problem in a holistic, multidisciplinary, and practical manner. Either we tend to believe that all ill effects in urban waters are due to pollutants or we feel the problem is overblown and too difficult to resolve.

Multiple Sources

Part of this dichotomy is based in the reality that we release tens of thousands of chemicals from multiple sources and generate pollutants from our many activities. Added to that, these chemicals can be modified by oxidation and evaporation, thus their toxic and physical properties can change. They end up in water, settle down in sediment, and are recirculated in water and air. Polychlorinated biphenyls (PCBs), aromatic hydrocarbons (AHs) from urban runoff and oil spills, and heavy metals from industry are just a few of the chemicals going into marine ecosystems. Adding to this complexity, when we speak of assessing effects of pollution on aquatic ecosystems we are talking about many different phyla and species, as opposed to human health studies that concern only one primary species. Although it is frustrating and one may feel that science and scientists are not providing answers about how pollutants affect ecosystems, we must temper that frustration with understanding. If biomedical science, on which much more effort is spent and which is focussed only on humans, still has a long way to go in solving many health problems, it is logical that environmental science, with its limited resources but almost limitless scope, has only begun to solve pollution problems.

Identifying Relationships Between Contaminants and Deleterious Effects

The comprehensive and overwhelming nature of the problem notwithstanding, it is possible to progress systematically and logically by developing a set of key questions that must be answered when confronted with the plethora of biological effects occurring in urban waters, such as liver tumors, reproductive dysfunction, immunological dysfunction, and fin erosion in fish; mass mortality of marine mammals; and growth impairment in juvenile fish and invertebrates. The primary question to ask: Is there a link between contaminants and these effects? If a link is shown, which contaminants consistently appear as risk factors (also, which natural factors enhance these risk factors), and at what level do these effects occur? Since contaminants can be measured in minute quantities, we can find them everywhere. It is critical that we know at what level a contaminant becomes toxic and causes serious biological damage. We must also ask if the proper methods are being used for the particular contaminants and species we are working with.

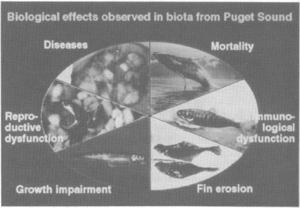

Figure 1. Some biological effects, such as diseases, reproductive dysfunction and immunological dysfunction, have been linked with the presence of certain contaminants.

To answer these questions, our research team set several goals and developed a multidisciplinary strategy. To assess a particular adverse biological effect observed in organisms in urban waters, we established a strategy to (a) determine cause and effect relationships between contamination and the adverse effect, (b) identify consistent chemical and biological risk factors for such an effect, (c) develop a large database that can generate information as to the level of a group of contaminants in sediment which can initiate the deleterious effect, and, most importantly, (d) develop a suite of diagnostic tests, or biomarkers, that can be used for screening and identifying early effects in organisms exposed to contaminants. We learned early on that we must work together with scientists and natural resource managers from many backgounds, using a multidisciplinary approach which includes both lab and field studies. This research strategy was not developed overnight but over several years by trial and error, and is now a routine procedure in any study, such as in the research described below.

Hydrocarbons and Liver Tumors

In the late 1970s, scientists from several laboratories reported liver tumors in bottom fish from Puget Sound and other coastal areas around the U.S. and Canada. These incidences were always in urban waters. Because many cancer-causing pollutants settle in sediment, bottomfish feeding on worms and other creatures may accumulate these contaminants. After many years of sampling several thousand fish, we could definitely conclude that the liver tumors and many other lesions visible under the microscope were present only in fish from urban areas, and that levels of hydrocarbons in sediment were strongly associated with cancer prevalence. Data from field studies on the prevalence of liver tumors showed a strong link to hydrocarbons, which come from oil, creosote, and other non-point sources, but no consistent link was shown between liver tumors and PCBs. We also conducted a major laboratory study lasting over a year to show that contaminants, separated from urban sediment containing high levels of hydrocarbons, produce lesions in healthy fish, but not tumors, which appear *in field only* in fish two years or older. These lesions are similar to those found in fish from urban waters.

Interestingly, the fish tissues did not show measurable levels of polycyclic aromatic hydrocarbons (PAHs). This finding led to a multi-year study to show that fish convert PAHs to more water-soluble products (metabolites) that accumulate in the gall bladder. This line of study resulted in the development of a method that can measure levels of metabolites in bile, thus providing an estimate of exposure of fish to PAHs. This is an important development because, unlike English sole, many bottomfish are relatively mobile and, hence, levels of contaminants in sediment may not always be a useful indicator of exposure. The "bile method" also turned out to be much faster and less expensive than traditional methods used to analyze PAHs in tissues. This method was used aboard ships and at the sites of fish capture in the aftermath of the *Exxon Valdez* oil spill in Alaska and the Persian Gulf oil spill to provide real-time analyses of exposure of fish to hydrocarbons.

DNA Damage

Another finding from these studies was that although many PAHs are metabolized, during the metabolism of PAHs in liver, some metabolites are bound to DNA, and thus modify the genetic material. We have refined and automated a method (post-labelling method) that allows us to quantify levels of metabolites bound to DNA. We can also obtain a pattern, or profile, of DNA adducts which gives an insight into the types of contaminants that fish have been exposed to in urban waters. This measurement also gives information about the damage to DNA, which is believed to be an important biomarker for liver cancer (tumor).

The approach used in these studies was applied nationwide. Over several years, bottomfish and sediment from over 70 sites were analyzed annually to determine the prevalence of liver lesions, levels of PAHs or metabolites and other contaminants in sediment and tissues, and to determine age and gender of fish to develop information on consistent risk factors for liver disease in fish. It was clearly shown that PAHs and age were consistent risk factors, while PCBs, DDTs, metals, and gender were not consistently associated with liver lesions. Although PCBs do not directly act as cancer causing compounds, they may promote tumor formation. The results also validated the use of precancerous lesions and DNA adducts as diagnostic tools for testing the "ecological health" of the coastal areas in terms of prevalence of fish diseases. The next question was whether fish with liver diseases will have reduced reproductive capacity and, if so, whether such an effect can lead to population level effects.

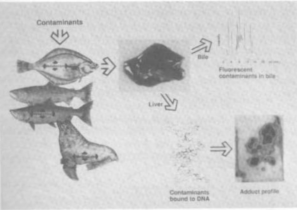

Figure 2. Processing of some organic contaminants by fish and mammals.

Reproductive Impairment

A multi-year study was conducted with about 1,000 fish to show that female fish were failing to mature sexually and that those that matured had low spawning success. The bottom fish in contaminated waters had low levels of sex hormones at certain levels of PAHs in bile, thus indicating that hormone levels may be a good biomarker or diagnostic tool to assess the reproductive capacity of the female population. The next question was: if this dysfunction leads to reduced fecundity in fish, would the reduction be at a level where there would be a measurable impact on the population?

The result of sophisticated treatment of data in a projection model showed that, indeed, if all other factors were kept constant—factors such as environmental fluctuation and recruitment—levels of contamination in sediment from the three urban sites, in comparison to a relatively clean control site, were sufficient to cause declines in the population of certain year classes. Such data should be useful in making management decisions about whether to reduce contamination at these sites to levels where no effect on populations can be discerned, to alter fishing pressure on these fisheries to make up for contaminant-induced loss, or to make an informed decision that the loss due to contamination was too insignificant compared to natural variations in population of this particular fishery.

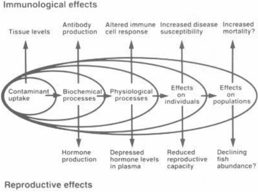

Figure 3. The process of contaminant uptake affecting populations involves a series of steps, each with its own immunological and reproductive indicator.

Immunosuppression in Juvenile Salmon

Until now I have discussed fish that reside in sediment, but as we were able to develop biomarkers that can detect short-term effects and exposure in fish that are mobile, we addressed a very important question: Do young salmon that pass through urban waters accumulate any of these chemicals? We collected juvenile chinook salmon from hatcheries and from three estuaries in Puget Sound two weeks after the fish were released from the hatcheries. We sampled salmon from two contaminated estuaries and one relatively clean one and found that indeed fish had accumulated hydrocarbons and PCBs via the food chain and showed biochemical changes in liver. Fish also showed depression in their immune systems, which can be brought about in laboratory studies with hatchery fish exposed to the same chemicals present in urban sediment. The question we now need to answer is whether the alteration in immune competence of these fish affects their ability to resist disease organisms (bacteria, viruses) in the wild and if that, in turn, will affect their early ocean survival. In addition, we need to identify which groups of contaminants cause effects, how long dysfunction persists, and how early ocean survival is affected. Because of the migrating habits of salmon, we can only run studies for a short period each year, but with each study we add another piece of information to this puzzle.

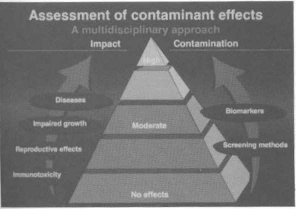

Figure 4. Application of early indicators in the assessment of impact of chemical pollution on the health of marine organisms.

With immune dysfunction, as with all the effects I have discussed, we focus not just on the type of chemicals associated with the effect, but also the threshold levels. Accounting for the threshold level is part of the process of taking in all the available information on the contaminants, the species in which the effects are observed, the ecosystem, and all other relevant biotic and abiotic factors. This information can then be used to develop early indicators of serious health effects in organisms in contaminated estuaries. The database of indicators can help us determine what actions need to be taken to maintain the integrity of the ecosystem, whether it is just monitoring to prevent further degradation or full-scale restoration.

Marine Mammal Strandings

In recent years, a number of grey whales have stranded in Puget Sound and San Francisco. As these are huge mammals that feed on sediment dwelling creatures, their being stranded in urban waters naturally caused alarm. Stomach contents of these whales contained large amounts of sediment which did have high levels of a variety of metals (some of the more natural components of sediment) and organic pollutants such as PAHs. However, when we analyzed the fish tissues we did not find high levels of contaminants. Unlike fish, one cannot sample grey whales, so we had to work with only stranded and degraded whale tissues. Therefore, we applied a different strategy to assess whether contamination was a significant factor in grey whale mortality. We analyzed stranded whales from pristine and urban waters and found no difference in levels and profiles of contaminants that would show an association between contamination at the site of stranding and tissue levels. The level of contaminants was much lower in grey whales than in harbor seals, sea lions, and porpoise. This is reasonable, as the diet of pinnipeds and cetaceans consists mainly of fish, which bioaccumulate a variety of pollutants, whereas grey whales feed lower on the food chain. I wanted to discuss these results to show that adverse effects found in urban waters do not necessarily indicate a cause and effect relationship. We must analyze each incident critically and answer the questions I presented above.

Moving Forward in Marine Pollution Studies and Restoration Involving the Public

Although I have discussed in detail the types of studies we perform to assess pollution problems in marine ecosystems, there is more to finding solutions than scientific hypothesis and experiments. In recent years we have come to realize the importance of including social and economic perspectives in assessing pollution impacts. The need to work with people became very clear after the *Exxon Valdez* oil spill in Prince William Sound, Alaska. The spill jeopardized the traditional food sources of many Native Americans in Alaska. We worked extensively with villagers through state agencies to familiarize them with the tests we were doing on their fish and shellfish, the chemicals we were screening for, and the

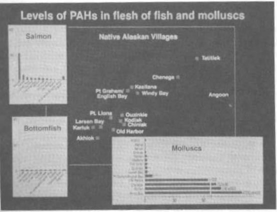

Figure 5. Concentration of total aromatic hydrocarbons in the edible flesh of subsistence fish and shellfish analyzed after the *Exxon Valdez* oil spill.

results we found regarding the safety of seafood consumption from oil-affected waters. It became apparent that, when the crisis and the actions it warrants are clearly and consistently explained, the general public can understand very complex scientific issues and work with scientific agencies to gain the most benefit from the research and its application. In addition to working with citizens during environmental emergencies, we have established working relationships with, and provide research information for, many citizen groups who are dedicated to preserving the coastal marine ecosystems.

Restoration Efforts

In working with citizens and public groups, I am often asked about the viability and success of various restoration efforts. It is important to keep in mind that at present we do not have all the knowledge needed to guarantee that restoration actions won't do further damage to ecosystems. However, it is no longer believed that all polluted areas need to be or can be completely restored; the focus is on what needs to be and can be done at each individual site. The knowledge of cause and effect relationships and tolerance levels (thresholds) should help us to decide what level of restoration efforts will be needed to obtain a sustainable and healthy ecosystem. For instance, we know that for oil spills, attempts to clean up the affected area sometimes do more harm than good, yet, due to lack of knowledge, there is still pressure to clean up a spill just to be "doing something." We need to test cleaning and restoration methods in non-emergency situations to determine whether the damage done to biota and their habitat by the restoration is worth the good it will do. Then, we must make these choices bravely and logically.

We are testing the efficacy of some restoration techniques that are used in certain situations. For instance, capping a clean layer of sediment on top of contaminated sediment is sometimes done to prevent further input from the contaminated sediment into the ecosystem, and provide a relatively cleaner habitat for benthic biota. This method has been used in Eagle Harbor, Washington, a site on the U.S. Environmental Protection Agency's Superfund list. We are measuring levels of contamination and certain reversible, physiological changes in fish before, during and after capping to see how effective the capping is. Other restoration techniques include moving contaminated sediment to areas with little biota, and using cultured organisms that normally "eat" or degrade harmful chemicals to clean a contaminated area.

Conclusion

Considering restoration methods and some of the successes we have had is one way to look at the future of our marine resources without feeling pessimism. Of course, we must face the reality that many urban marine ecosystems are endangered. Habitat loss, overfishing, introduction of exotic species, UV radiation, and a host of effects from pollution all threaten the health and productivity of marine species, including valuable fishery stocks. Although we have made progress in developing methods to screen for chemicals, as well as methods to indicate early signs of stress in biota that these chemicals cause, there is still much work to be done. It is important that we continue to take a multidisciplinary, holistic approach to these problems by asking questions, establishing relationships, developing techniques, and then providing marine resource managers, citizen groups and individuals with timely information. When sound science is provided, along with sociological and economic input, we will be ready to address marine resource problems with hope and optimism.