MAKING SCIENCE USEFUL IN COMPLEX POLITICAL AND LEGAL ARENAS: A CASE FOR FRONTLOADING SCIENCE IN ANTICIPATION OF ENVIRONMENTAL CHANGES TO SUPPORT NATURAL RESOURCE LAWS AND POLICIES

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In the spirit of fostering interdisciplinary dialogue, the Washington Journal of Environmental Law and Policy is proud to present this Article. Professor Varanasi takes examples from her career as a fisheries scientist for the National Oceanographic and Atmospheric Administration to argue for a new model for ecological disaster planning and response, in which baseline ecosystem data is collected in advance of possible incidents so that decision-makers are empowered

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I joined the National Oceanic and Atmospheric Association (NOAA) in 1975 and served as the Science and Research director of Northwest Fisheries Science Center (NWFSC) from 1994–2010. The case studies described herein are the work of many current and erstwhile scientists in NOAA mentioned in the bibliography. Specific thanks go to Mark Myers, who provided input to the Case study 1b, and Robin Waples who provided input to the Case study 2 while also kindly reviewing several drafts. Thanks are also due to John Stein, Gina Yltalo, Jon Incardona, Nathaniel Scholz, Mike Ford, Stanley (Jeep) Rice, Timothy Beechie and Tom Hom for patiently providing references and explanations of their research findings and reviewing sections of this paper. Lastly but very importantly, I thank Arianne Duong, UW School of Pharmacy, who helped me organize my files and my thoughts with her fresh perspective and excellent editorial support for many drafts of this paper, and the College of the Environment and the School of Aquatic and Fisheries Sciences for providing financial support to Arianne.

My special thanks to Professor William Rodgers, UW School of Law, for inviting me to co- teach a class, Law B565 U.S. Coastal and Ocean Law *aka* "Our oceans in legal crisis," which crystallized my thoughts about critical applications of science, not only as a service for the policy makers but as a legal requirement/tool that demands that the best available science must underpin implementation of Nation's environmental and conservation laws. He also took time out of his busy schedule to review this paper. I also thank Cynthia Fester and the administrative staff of the law school for providing ever-ready assistance. I enjoyed my interactions with the students of our class B565, especially Valerie Rickman, who invited me to submit this paper to the WJELP. I would also like to thank Tom Wheeler for guiding me through the intricacies of formatting this paper for a law journal, which is very different from the scientific articles I normally publish. Finally, I would like to thank Denis Hayes, Bullitt Foundation, for his encouragement and suggestions as I began my work on this topic.

to make informed choices from the first stages of disaster response. She concludes by urging sustained and targeted funding for long-term ecosystem data collection to better understand various disasters' effects on a region and to improve prospects for restoration of the degraded ecosystem and recovery of species.

—2012–13 Editorial Board

I. INTRODUCTION

It is a given that environmental and natural resource science must operate in a complex political and legal climate, often under the bright spotlight of public scrutiny. This is nowhere more apparent than during major environmental disasters. For example, it has been just over three years since the Deepwater Horizon (DWH) oil drilling well for British Petroleum (BP) in the Gulf of Mexico exploded. The ecosystems and waters of the Gulf Coast have been exposed to an estimated 4.9 million barrels of spilled oil as well as a massive amount (1.8 million gallons) of chemical dispersant used with the intention of preventing the oil from reaching the shoreline of the five Gulf states.[1] With its disastrous impact on the Gulf Coast's ecology and economy, this spill has presented a great challenge, especially to scientists[2] who frantically gather thousands of samples from impacted areas and, under dynamic conditions, try to generate numerous data reports to inform a concerned public. Although this spill has been called an unprecedented challenge,[3] it is similar to previous major spills[4] and storms[5] in one critical aspect: it demonstrates *once more* that the assessment of injury to natural resources can be seriously hampered by lack of knowledge about the prior state

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1. Campbell Robertson and Clifford Krauss, *Gulf Spill is the Largest of Its Kind, Scientists Say*, N.Y. TIMES, Aug. 2, 2010, http://www.nytimes.com/2010/08/03/us/03spill.html; *see also* Jane Lubchenco et al, *Science in support of the Deepwater Horizon response*, 109 PROC. NATL. ACAD. SCI. 20222-20228 (2012); CARL SEFINA, A SEA IN FLAMES: THE DEEPWATER HORIZON OIL BLOWOUT (2011); Marcia K. McNutt et al., *Application of Science and Engineering to Quantify and Control the Deepwater Horizon Oil Spill*, 109 PROC. NATL. ACAD. SCI. 20212 (2012).

2. Robertson, *supra* note 1; Lubchenco et al., *supra* note 1.

3. Robertson, *supra* note 1; Lubchenco et al., *supra* note 1.

4. NAT' L COMMISSION ON THE BP DEEPWATER HORIZON OIL SPILL & OFFSHORE DRILLING, REPORT TO THE PRESIDENT, DEEP WATER: THE GULF OIL DISASTER AND THE FUTURE OF OFFSHORE DRILLING 260–61 (Jan. 11, 2011), *available at* http://docs.lib.noaa.gov/noaa_documents/NOAA_related_docs/oil_spills/DWH_report-to-president.pdf; *see also* EVALUATING AND COMMUNICATING SUBSISTENCE SEAFOOD SAFETY IN A CROSS-CULTURAL CONTEXT: LESSONS LEARNED FROM THE EXXON VALDEZ OIL SPILL 338 (L. Jay Field et al. eds., Society of Environmental Toxicology and Chemistry) (1999); AMERICAN FISHERIES SOCIETY SYMPOSIUM 18, PROCEEDINGS OF THE EXXON VALDEZ OIL SPILL SYMPOSIUM 463 (Stanley D. Rice et al. eds., 1996); Usha Varanasi, *Frontloading the Science in Anticipation of Environmental Disasters*, 37 FISHERIES 233 (2012).

5. Tom Hom et.al., *Assessing Seafood Safety in the Aftermath of Hurricane Katrina*, AMERICAN FISHERIES SOCIETY SYMPOSIUM 64, MITIGATING THE IMPACTS OF NATURAL HAZARDS ON FISHERY ECOSYSTEMS 73 (Katherine D. McLaughlin ed., 2008).

of the affected ecosystem.[6]

Our coasts and oceans routinely experience significant environmental crises, and when they do, environmental managers, regulators, scientists, legal experts, stakeholders, non-governmental organizations (NGOs), media and the public at large respond valiantly and determinedly. After each massive oil spill or super storm, national commissions[7] or review boards convene to determine what went wrong and why the most advanced nation on the planet has not averted or constrained these catastrophes through better forethought, scientific knowledge, and planning. After each major crisis, there is a general consensus[8] that a robust scientific basis (or underpinning) and baseline data should be available beforehand. Invariably, once the fervor and frenzy over the catastrophe subside and the crisis moves off of the center stage, funding and momentum are cut short and institutional memories begin to fade.[9]

I strongly urge that we must stop thinking about funding good and relevant science "if and when" disasters happen. They are inevitable, and we must ensure that robust scientific inquiry is conducted and supported between disasters when there are opportunities to expand our scientific and technological capacity thoughtfully and strategically. It is imperative that we become better prepared before the next "big one" hits us, rather than scrambling to reinvent the wheel. In short, it is crucial to be ahead of the curve (i.e., frontload the science) and look for novel approaches to fund science if traditional approaches are insufficient. The premise "frontloading of science" used in this paper pertains to empirical research and/or synthesis of existing scientific information needed to address management of ecosystems and species under duress. However, I should emphasize that the "discovery science," which by its very nature is at the frontier

6. *Deepwater Horizon: Updating OPA*, THE ENVTL. FORUM, September/October 2010, at 46; *see also* Rebecca M. Bratspies, *A Regulatory Wake-Up Call: Lessons from BP's Deepwater Horizon Disaster,* 5 GOLDEN GATE U. ENVTL. L.J. 7, 28 (2011).

7. *Nat'l Commission on the BP Deepwater Horizon Oil Spill & Offshore Drilling*, *supra* note 4; Field et al., *supra* note 4.

8. *Nat'l Commission on the BP Deepwater Horizon Oil Spill & Offshore Drilling*, *supra* note 4; Varanasi, *supra* note 4.

9. Varanasi, *supra* note 4; *Deepwater Horizon: Updating OPA*, *supra* note 6; Bratspies, *supra* note 6.

of knowledge, is critical to provide us with a fundamental basis for our understanding of a species and ecosystem interactions.

In this article, I will discuss how the lack of upfront funding and planning, coupled with lack of appreciation of the inherent nature of science, contributes to the declining trend in America's ability to use science to assess future threats—especially in complex political and legal climates that impose short deadlines and focus on reacting to immediate crises demanding attention. I propose that the frontloading of science—the accumulation of holistic scientific understanding and data ahead of time—is crucial as a means to anticipate environmental change and to improve planning and public policy. Long-term monitoring and evaluation of effectiveness are necessary to ensure that the application of science has the intended effects, and to allow for the generation of valuable data. I will also describe two case studies that illustrate the benefit of such frontloading.

II. MAKING A CASE FOR THE FRONTLOADING OF SCIENCE AS PART OF A SOLUTION TO MANAGEMENT CHALLENGES

It is essential to frontload science because of its inherent peculiarities and limitations. Policymakers must consider these constraints and ensure that robust and timely scientific underpinning is developed beforehand.

Science is slow to mature. It is an ongoing process that evolves with time, and this inherent characteristic does not easily mesh with the need to make policy decisions under a tight timeframe. Sometimes litigating parties are forced to use immature science, which cannot withstand intense scrutiny.

Uncertainty is inherent in science. Long-term time series and vast amounts of data are necessary to reduce uncertainty. Policy-makers crave certainty, and hence they should be mindful of this characteristic of scientific inquiry.

The peer review/publication process is what separates science from opinion. But during peer review, deficiencies are openly discussed and hence are often used by litigating parties to create doubt about the quality of the science.

Science continues to evolve, as can be seen in the medical and nutritional fields. But we must gather knowledge reliably to reduce uncertainty while making decisions that may have to be revisited. The evolution of scientific understanding and discovery can lead to a paradigm shift, and we must be nimble enough to rethink our fundamental premises.[10]

Despite the challenges presented by these inherent properties of science, a solid scientific foundation must remain available in the context of environmental disasters and chronic degradation. This foundation is indispensable in all endeavors to restore degraded ecosystems and respond to natural resource damage claims. Both undertakings require scientific expertise to understand natural baselines, biological processes, and prospects for recovery.

A. *The Frontloading of Science is a Two-Way Responsibility*

It is imperative for scientists to be prepared for environmental change—be it a slow degradation or a sudden disaster—and to take leadership to prescribe a robust scientific framework that is ready to be used by managers, litigators and policymakers. Policymakers in turn should deliver sustained funding and demand that the best available science underpin the implementation of national mandates and environmental laws enacted to protect fragile coastal and ocean ecosystems from anthropogenic pressures.

Below I describe two types of case studies from the National Oceanic and Atmospheric Administration's (NOAA's) Northwest Fisheries Science Center (NWFSC),[11] where I worked for over three decades. These case studies are successful examples of frontloading science where scientists persevered using bold strategies that proved useful in numerous management challenges. While I describe the two case studies I am most familiar with, it should be noted that work of other federal agencies, state governments, academia,

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10. Tim Beechie and Susan Bolton, *An Approach to Restoring Salmonid Habitat-Forming Processes in Pacific Northwest Watersheds*, 24 FISHERIES 4, 6–15 (1999); *see also* Timothy J. Beechie et al., *Process-Based Principles for Restoring River Ecosystems*, 60 BIOSCIENCE 209 (2010); Timothy J. Beechie et al., *Restoring Rivers in the 21st Century: Science Challenges in a Management Context*, *in* THE FUTURE OF FISHERIES SCIENCE IN NORTH AMERICA 697 (Richard J. Beamish and Brian J. Rothschild eds., 2009); T. Beechie et al., *Restoring Salmon Habitat for a Changing Climate*, 29 RIVER RESEARCH AND APPLICATIONS 939 (2012); James Battin et al., *Projected Impacts of Climate Change on Salmon Habitat Restoration*, 16 PROC. NATIONAL ACADEMY 6720 (2007).

11. The NWFSC established in 1988 is the science arm of the National Marine Fisheries Service (NMFS) in the northwest. Its predecessor organization was the Northwest & Alaska Fisheries Science Center. The regulatory branch of NMFS in the NW region implements the Endangered Species Act and other regulatory mandates, including subsequent recovery plans for anadromous and marine species.

and even NGOs contribute to the scientific enterprise.

The first case study utilized empirical research to develop new understanding of biological processes, and the second case study synthesized existing scientific information—developed over decades—using innovative procedures. Both examples demonstrate the power of sustained frontloading of science that continues to provide timely scientific underpinning for critical management actions in times of environmental emergencies and degradation.

B. *Case Study 1a: Frontloading of Science in Response to Chronic Degradation of Ecosystems*

Soon after I joined NOAA in 1975, a vessel named the *Argo Merchant* sank off of Nantucket Island, Massachusetts in December 1976. The sinking resulted in several million gallons of Bunker C fuel oil spilling into the surrounding marine environment. This disaster reemphasized long-standing concerns about the potentially deleterious impacts of petroleum transport and drilling in the marine environment. In the mid 1970s, the Outer Continental Shelf Ecosystem Assessment Program (OCSEAP) was established to investigate the impacts of potential leaking of petroleum from the Trans-Alaska Pipeline System (TAPS), which was planned as a means to transport crude oil from Alaska's North Slope to Valdez for shipping to other destinations. TAPS was built between 1974 and 1977 and has been in continuous operation since then.[12] As TAPS was being built, the National Academy of Sciences published an overview of the fate, transport, and effects of petroleum in the marine environment, indicating that there were considerable gaps in knowledge of the uptake and effects of petroleum on sea life.[13]

My early research was funded by OCSEAP to understand how vertebrates (e.g., fish and marine mammals) and invertebrates (e.g., mollusks and shellfish) would take up and process polycyclic aromatic hydrocarbons (PAHs)—well known toxic components of crude oil—from their environment.[14] Also,

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12. Alyeska-pipe.com, Pipeline Facts, http://www.alyeska-pipe.com/TAPS/PipelineFacts (last visited Nov. 23, 2013).

13. NAT'L RESEARCH COUNCIL, PETROLEUM IN THE MARINE ENVIRONMENT (E. Bright Wilson ed., 1975).

14. Usha Varanasi and Donald C. Malins, *Metabolism of Petroleum Hydrocarbons:*

under this program, a study was planned to determine the prevalence of liver and skin lesions in Alaskan bottom fish from the coast near where the pipeline was going to be installed. The purpose of this study was to establish the baseline upon which to assess injury in cases of leaks or spills.[15] In the early 1970s scientists in Auke Bay Laboratory of Northwest and Alaska Fisheries Science Center had begun to develop information on the baseline levels of petro-genic hydrocarbons in intertidal sediments and mussels of Prince William Sound, Alaska.[16]

For me, OCSEAP was the first example of planning ahead of an incident or crisis. As a chemist joining NOAA to work on OCSEAP, I was intrigued by studies showing that the fish sampled from near oil spills did not show detectable concentrations of PAHs in their tissues.[17] A number of hypotheses were discussed during meetings held in the mid-1970s at NOAA's Montlake laboratory in Seattle, WA. One hypothesis was that fish were unable to absorb these large hydrophobic (relatively insoluble in water) PAHs from their environment. Moreover, an early laboratory study had implied that compared to rat or mice liver preparations, fish liver extracts had a very low capacity to convert or metabolize hydrophobic PAHs to more water soluble products (metabolites).[18] However, around the same time, my colleagues were reporting a strong correlation between levels of organic pollutants—especially cancer-causing PAHs present in the

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Accumulation and Biotransformation in Marine Organisms, EFFECTS OF PETROLEUM ON ARCTIC AND SUBARCTIC MARINE ENVIRONMENTS AND ORGANISMS, VOL II 179 (Donald C. Malins ed., 1977).

15. C.E. Alpers et al., *Pathologic Anatomy of Pseudobranch Tumors in Pacific Cod Gadus macrocephalus*, 54 J. NATL. CANCER INST. 377 (1977); Bruce McCain et al., *The Frequency, Distribution and Pathology of Three Diseases of Demersal Fishes in the Bering Sea,* 12 J. FISH BIOL. 267 (1978); Bruce B. McCain et al., *Tumors and Microbial Diseases of Marine Fishes in Alaskan Waters*, 2 J. FISH DISEASES 111 (1979).

16. JOHN .F. KARINEN ET AL., DEPT. OF COM., HYDROCARBONS IN INTERTIDAL SEDIMENTS AND MUSSELS FROM PRINCE WILLIAM SOUND, ALASKA, 1977-1980: CHARACTERIZATION AND PROBABLE SOURCES 70 (Jan. 1993).

17. Papers cited in EFFECTS OF PETROLEUM ON ARCTIC AND SUBARCTIC MARINE ENVIRONMENTS AND ORGANISMS: VOLUME I–II (Donald C. Malins ed., 1977); papers cited in METABOLISM OF POLYCYCLIC AROMATIC HYDROCARBONS IN THE AQUATIC ENVIRONMENT (Usha Varanasi ed., 1989).

18. Papers cited in Donald R. Buhler and David E. Williams, *Enzymes Involved in Metabolism of PAH by Fishes and Other Aquatic Animals: Oxidative Enzymes (or Phase 1 Enzymes), in* Usha Varanasi ed., *supra* note 17.

bottom sediment of highly contaminated sites in Puget Sound, WA—and the prevalence of liver tumors in a sedentary bottom fish, the English sole (*Parophrys vetulus*).[19] These findings implied that bottom fish were able to absorb these petro-genic and pyrogenic PAHs, and must be converting them in the liver into metabolites since original or parent PAHs were not detected in tissues of fish.

1. *Understanding Biochemical Processes to Develop Methods for Seafood Safety Monitoring*

To solve this puzzle, my small team and I conducted laboratory studies in which we treated bottom fish sampled from relatively clean sites in Puget Sound with radiolabeled PAHs including benzo(a)pyrene, which is a known carcinogen present in fossil fuels and also found in contaminated sediments in urban estuaries.[20] Measuring radioactivity in tissues and bile of treated fish, we found that the PAHs were readily absorbed (or taken up) by the fish and extensively transformed in the liver to metabolites that were excreted into the gall bladder.[21] These findings explained why there was

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19. B.B. McCain, et al., *Bioavailability of Crude Oil from Experimentally Oiled Sediments to English Sole Parophrys vetulus and Pathological Consequences*, 35 J. FISH. RES. BD. CANADA 657 (1978); Donald C. Malins et al., *Chemical Pollutants in Sediments and Diseases in Bottom-Dwelling Fish in Puget Sound, Washington*, 18 ENVTL. SCI. TECH. 705 (1984); Mark S. Myers et al., *Pathologic Anatomy and Patterns of Occurrence of Hepatic Neoplasms, Putative Preneoplastic Lesions and Other Idiopathic Hepatic Conditions in English Sole (Parophrys vetulus) from Puget Sound, Washington*, 78 J. NAT'L CANCER INST. 333 (1987); M.S. Myers et al., *Overview of Studies on Liver Carcinogenesis in English Sole from Puget Sound; Evidence for a Xenobiotic Chemical Etiology I: Pathology and Epizootiology*, 94 SCIENCE OF THE TOTAL ENVIRONMENT 33 (1990); Mark S. Myers et al., *Toxicopathic Hepatic Lesions in Subadult English Sole (Pleuronectes vetulus) from Puget Sound, Washington, USA: Relationships With Other Biomarkers of Contaminant Exposure*, 45 MARINE ENVTL. RESEARCH 47 (1998).

20. Myers et al., *Overview of Studies on Liver Carcinogenesis in English Sole from Puget Sound*, *supra* note 19; Myers et al., *Toxicopathic Hepatic Lesions in Subadult English Sole, supra* note 19; Varanasi, *supra* note 17; Usha Varanasi and Dennis. J. Gmur, *In Vivo Metabolism of Naphthalene and Benzo(a)pyrene by Flatfish*, *in* CHEMICAL ANALYSIS AND BIOLOGICAL FATE: POLYNUCLEAR AROMATIC HYDROCARBONS 367 (Marcus Cooke and Anthony J. Dennis eds., 1981); Dennis. J. Gmur and Usha Varanasi, *Characterization of Benzo(a)pyrene Metabolites Isolated From Muscle, Liver and Bile of Juvenile Flatfish*, 3 CARCINOGENESIS 1397 (1982).

21. Papers cited in Varanasi ed., *supra* note 17; *see also* Usha Varanasi, *Hydrocarbon Metabolism in Flatfish,* 2 COASTAL OCEANOGRAPHY AND CLIMATOLOGY NEWS 17 (1980); Varanasi and Gmur, *supra* note 20; Gmur and Varanasi, *supra* note 20.

little or no deposition of the parent PAHs into edible tissues (e.g., muscle) of the fish.[22] These results demonstrating that fish efficiently processed PAHs led to the development of a number of techniques, including an analytical method that could rapidly measure the fluorescent metabolites of PAHs in the bile fluid of fish.[23] This method is highlighted because it became a key element for responding effectively to seafood safety and biological impact concerns following oil spills or after exposure to contaminants in urban estuaries.

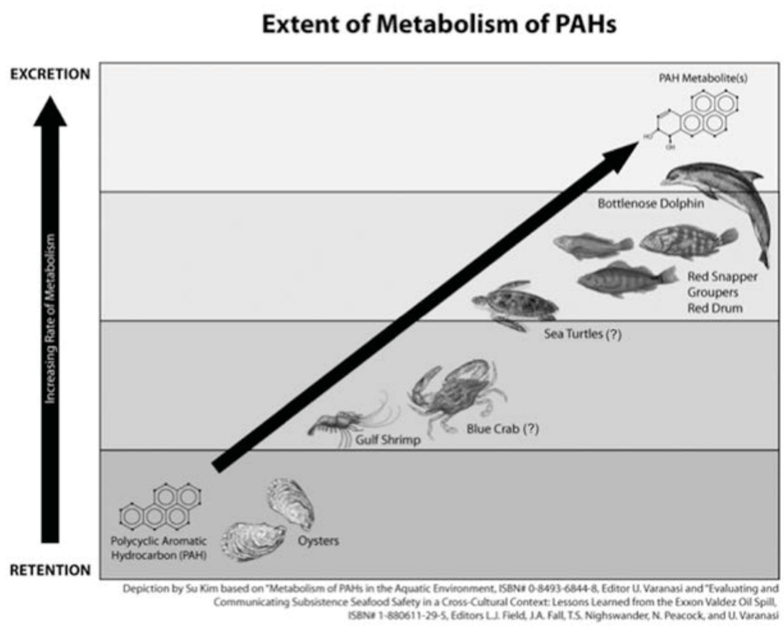

Figure 1. Extent of metabolism of a model polycyclic aromatic hydrocarbon in marine biota .

Since the PAHs do not accumulate in tissues of vertebrates, consumers of fish have little or no threat of exposure to PAHs through this food chain (Figure 1). The flip side of this phenomenon is that when PAHs are metabolized, a small fraction gets bound to liver DNA (referred as PAH-DNA adducts).[24] The formation of PAH-DNA adducts is considered

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22. Varanasi and Gmur, *supra* note 20.

23. Margret M. Krahn et al., *Determination of Mixtures of Benzo[a]pyrene, 2,6-dimethylnaphthalene and their Metabolites by High-Performance Liquid Chromatography with Fluorescence Detection*, 113 ANALYTICAL BIOCHEMISTRY 27 (1981); MARGRET M. KRAHN ET AL., U.S. DEPT. OF COMMERCE, METABOLITES OF AROMATIC COMPOUNDS IN FISH BILE, NOAA TECH. MEMO NMFS F/NWC-102 (1986).

24. Usha Varanasi et al., *Comparative Metabolism of Benzo(a)pyrene and Covalent*

to be one of the first steps in developing cancer (carcinogenesis) in PAH-exposed vertebrates including humans.[25] Hence the early research of the Northwest Fisheries Science Center (NWFSC) scientists coupled with the subsequent development of a novel technique the DNA adducts in fish liver[26] and measurement of fluorescent PAH metabolites and early or pre-neoplastic precancerous liver lesions, helped to establish a cause and effect relationship between high levels of PAHs and related polycyclic aromatic compounds (PACs) in sediment and prevalence of liver cancer in benthic fish from contaminated areas in Puget Sound.[27] Based on the research described above, liver tumors in benthic fish from contaminated estuaries were accepted as an important index of pollution-induced biological damage in natural resource damage law suits against Potentially Responsible Parties under The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund litigation.[28] The peer-reviewed scientific information from the NWFSC was frontloaded to design a suite of biomarkers to monitor and evaluate effectiveness of habitat remediation of contaminated sediments at a superfund site in Puget Sound, as described below.

Binding to Hepatic DNA in English Sole, Starry Flounder, and Rat, 46 CANCER RESEARCH 3817 (1986).

25. Werner K. Lutz, *In Vivo Covalent Binding of Organic Chemicals to DNA as a Quantitative Indicator in the Process of Chemical Carcinogenesis*, 65 MUTATION RESEARCH 289 (1979); *see also* C.S. Cooper et al., *The Metabolism and Activation of Benzo(a)pyrene*, PROGRESS IN DRUG METABOLISM VOL. 7 295 (J.W. Bridges and L.F. Chasseaud eds., 1983).

26. Ramesh C. Gupta et al., *^{32}P-Postlabeling Analysis of Non-Radioactive Aromatic Carcinogen-DNA Adducts*, 3 CARCINOGENESIS 1081 (1982); *see also* William L. Reichert and Usha Varanasi, *Detection of Damage by ^{32}P-Postlabeling Analysis of Hepatic DNA in English Sole From an Urban Area and in Fish Exposed to Chemicals Extracted from the Urban Sediment*, 28 PROC. AM. ASSOC. CANCER RESEARCH 95 (1987).

27. Myers et al., *Toxicopathic Hepatic Lesions in Subadult English Sole, supra* note 19; Mark S. Myers et al., *Establishing the Causal Relationship Between Polycyclic Aromatic Hydrocarbon (PAH) Exposure and Hepatic Neoplasms and Neoplasia Related Liver Lesions in English Sole (Pleuronectes vetulus),* 9 HUMAN AND ECOLOGICAL RISK ASSESSMENT 67 (2003).

28. TRACY K. COLLIER ET AL., U.S. DEPT. OF COMMER., NOAA TECH. MEMO. NMFS-NWFSC-29, FISH INJURY IN THE HYLEBOS WATERWAY OF COMMENCEMENT BAY, WASHINGTON (1998).

2. *Management Applications: Habitat Remediation and Monitoring*

Managers and scientists from NOAA, the Environmental Protection Agency (EPA) and the Washington Department of Fish and Wildlife (WDFW) agreed to use the suite of biomarkers in bottom fish discussed above to monitor the efficacy of capping of polycyclic aromatic compounds (PAC)-contaminated sediment with clean sediment in Eagle Harbor, an EPA designated superfund site in Puget Sound. This was a habitat remediation strategy used to reduce the risk to marine biota from exposure to high levels of PAC contamination.[29]

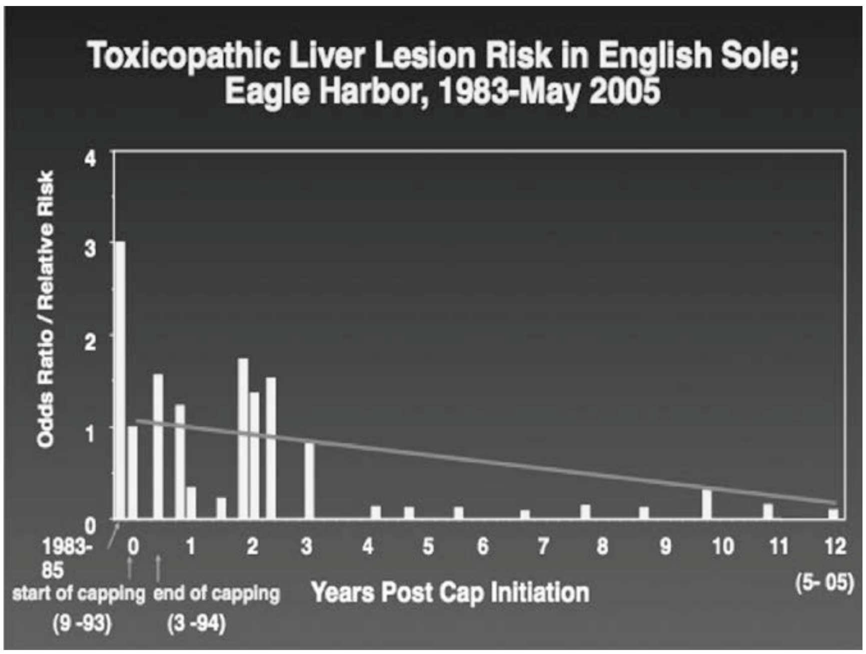

Figure 2. Monitoring of liver lesion risk in same age English sole sampled from Eagle Harbor, Puget Sound, Washington after heavily contaminated sediment was capped with clean sediment. Courtesy of Mark S. Myers, NWFSC (adapted from Myers et al 2008).

Monitoring of the above-mentioned biomarkers, which began in 1993 after the capping with clean sediment demonstrated that PAC exposure and attendant effects—namely liver lesions—were reduced significantly over nine years in a

29. Mark S. Myers et al., *Improved Flatfish Health Following Remediation of a PAH-Contaminated Site in Eagle Harbor, Washington*, 88 AQUATIC TOXICOLOGY 277 (2008).

resident species, English sole (Figure 2).[30]

3. *Consistent Funding and Long-Term Commitment are the Keys*

Unfortunately, the funding for this monitoring project has been a constant challenge due to budget constraints. The funding of long term monitoring programs is always challenging in a climate of annual budget cycles that require annual eye-catching results. This is against the very nature of long-term monitoring of trends!

Despite budgetary challenges, scientists from NWFSC and WDFW, recognizing the enormous value of long-term monitoring to the integrity of this remediated site, persevered with minimal funding in sampling English sole for nine more years. They were able to report that the risk of liver lesion occurrence in fish of the same age range actually increased from 3.3% in 2007 to 16.7% in 2011.This indicated that either the cap was breached or there was another source of contamination entering the Eagle Harbor site (Figure 2).[31] The findings offered a timely warning and were relayed to the EPA Region 10 to help choose further remediation options in Eagle Harbor and to garner their support to continue monitoring beyond 2013. This example demonstrates the value of long-term monitoring and evaluation of remediated or restored sites, as well as the importance of close communication and transfer of information between scientists and managers. Policy makers need to recognize this characteristic and the valuable contribution long term monitoring makes to managing and protecting fragile ecosystems, and should provide sustainable funding for such programs with built-in effectiveness measures to ensure that the program remains tractable.

C. *Case Study 1b: Response to Environmental Disasters (Oil Spills and Storms)*

The knowledge gained from early research[32] and the methods[33] developed were first applied during a field sampling

30. *Id.*
31. *Id.*
32. Papers cited in Varanasi ed., *supra* note 17.

effort following the 1989 EXXON Valdez oil spill (EVOS) in Prince William Sound, Alaska, to address issues of seafood safety and natural resource (sea life) damage assessment.[34]

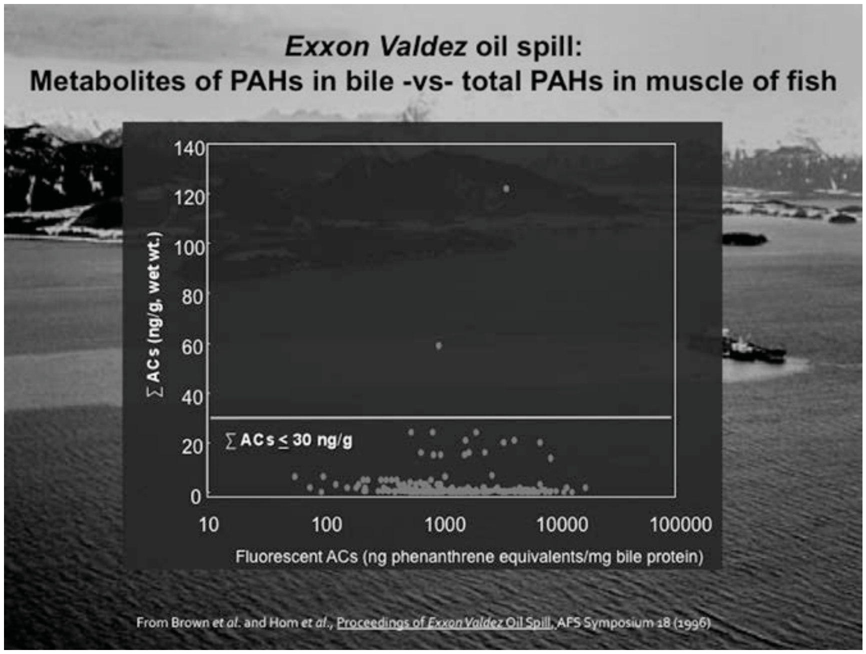

Figure 3. Comparison of PAH metabolites in bile and total PAHs in edible muscle from fish sampled after the Exxon Valdez oil spill in Alaska. (adapted from Rice et al., *supra* note 4 at 856)

Our earlier laboratory findings were validated when we examined muscle tissues and bile fluid from thousands of fish sampled from Prince William Sound and along the Alaskan coast after EVOS.[35] Analytical results revealed a wide range of exposure of fish to PAHs and related organic compounds present in the spilled oil (designated as PACs henceforth). As shown in Figure 3, even in fish with high levels of PAC

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33. Krahn et al., *Determination of Mixtures of Benzo[a]pyrene, 2,6-dimethylnaphthalene and their Metabolites by High-Performance Liquid Chromatography with Fluorescence Detection*, supra note 23; see also Reichert and Varanasi, supra note 26.

34. Usha Varanasi et al., Nat'l Marine Fisheries Service, Assessment of Oil Spill Impacts on Fishery Resources: Measurement of Hydrocarbons and their Metabolites, and their Effects, in Important Species, in Exxon Valdez Oil Spill State/Federal Natural Resource Damage Assessment Final Report (1995); Rice et al., supra note 4.

35. Tom Hom et al., *Measuring the Exposure of Subsistence Fish and Marine Mammal Species Exposed to Aromatic Compounds Following the Exxon Valdez Oil Spill*, in Field et al. eds., *supra* note 4 at 169.

metabolites in their bile, minimal or no contamination was detected in corresponding edible muscle tissue. This meant that, similar to our laboratory findings, fish sampled from oil-contaminated waters were efficiently metabolizing and excreting petroleum compounds, keeping edible tissue free from PAC contamination. Further, earlier laboratory and field studies had revealed that unlike vertebrate species (e.g., fish, mammals), invertebrate species such as mussels and clams could not metabolize PACs efficiently[36] and therefore accumulated high levels of toxic PACs. (Figure 1)[37] These results were used by managers of the Alaskan Oil Spill Health Task Force to determine the safety risk to Alaskan natives with regards to consumption of their subsistence seafood. Application of this knowledge has greatly improved real-time data needed to address the deep-seated public concerns of the safety of seafood following major environmental disasters such as hurricanes or oil spills.[38]

1. *The Consequences of Inconsistent and Insufficient Funding*

Regrettably, funding and support for scientific inquiry slowly declined over the years following EVOS. NOAA scientists have been applying the scientific approach developed before EVOS and used during EVOS[39] to more recent environmental disasters, including Hurricane Katrina[40] and

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36. Margaret O. James, *Biotransformation and Disposition of PAH in Aquatic Invertebrates*, *in* Varanasi ed., *supra* note 17, at 69; Michael N. Moore et al., *Hydrocarbons in Marine Mollusks: Biological effects and Ecological consequences*, *in* Varanasi ed., *supra* note 17, at 291.

37. Usha Varanasi et al., *Bridging Science and Policy: Challenges and Successes in Puget Sound*, 2011 SALISH SEA ECOSYSTEM CONFERENCE PROCEEDING (2011), *available at* http://www.salishseaconference.org/presentations_d3.php.

38. Varanasi, *supra* note 4; Hom et al., *supra* note 5; Gina M. Ylitalo et al., *Federal Seafood Safety Response to the Deepwater Horizon Oil Spill*, 109 PROC. NATL. ACAD. SCI. 20212 (2012); Hom et al., *supra* note 35; Donald W. Brown et al., *Exposure of Alaskan Subsistence Shellfish to Oil Spilled from Exxon Valdez, in* Field et al. eds., *supra* note 4 at 135.

39. Papers cited in Krahn et al., *Determination of Mixtures of Benzo[a]pyrene, 2,6-Dimethylnaphthalene*, *supra* note 23; Krahn et al., METABOLITES OF AROMATIC COMPOUNDS IN FISH BILE*, supra* note 23; Hom et al., *supra* note 5.

40. Hom et al., *supra* note 5.

the DWH spill,[41] to provide data about seafood safety and to inform agencies' decisions regarding fisheries management.[42]

My experience with environmental catastrophes in the EVOS and DWH incidents has shown that, despite the best efforts of dedicated scientists and agency staff there, was insufficient scientific information for serious decisions that had to be made when the nation responded to deep concerns over human safety, seafood contamination, damage to marine life and economic losses. For example, hot water cleaning was used on beaches during the EVOS to remove visible oil slicks from the rocks, and this method was relatively effective at removing the surface oil. Removing the surface oil may have prevented many surface dwellers (e.g., birds, mammals, invertebrates) from high risk exposures, but the high pressure surface cleaning may have driven the oil down into the sediments, into the anoxic zone, where it has persisted for at least two decades. Sea otters, for example, who forage in the lower half of the intertidal zone, continued to have population effects in the hardest hit areas. Disappointing, in both the EVOS and DWH spills, was the low rate of spilled oil recovery from the environment despite the employment of thousands of shoreline workers in EVOS, and hundreds of skimmers in DWH. While it is difficult to get an accurate accounting of the oil budget (i.e., percentage of spilled oil recovered, evaporated, burned, dispersed or retained in the compartments of the affected ecosystem), it appears that the actual recovery of spilled oil was very low compared to that released into the environment.[43]

The lack of sustained and targeted funding after EVOS and DWH has resulted in a glaring gap in advancement of knowledge and development of new technology. Specifically, there are insufficient methods to determine the uptake and toxicity of petroleum emulsified with dispersants, even though the use of chemical dispersants was identified as part of the response strategy after EVOS. To my knowledge, the responsible agencies have not devoted funding or attention to developing methods to test uptake or toxicity of dispersant components in marine organisms. During the DWH incident, a

41. Ylitalo et al., *supra* note 38.
42. Hom et.al., *supra* note 5; Ylitalo et al., *supra* note 38; Lubchenco, *supra* note 1.
43. Rice et al. eds., *supra* note 4; Sefina, *supra* note 1; McNutt et al., *supra* note 1.

massive amount of chemical dispersant (Corexit 9500A) was used to break up the oil mass in an attempt to protect shorelines and the public. However, scientists in the public sector could not measure the uptake of dispersant components or the effects of emulsified oil on marine organisms due to insufficient scientific knowledge.[44] The effect of such a large-scale use of dispersant (~1.8 million gallons) on the ecosystem of this region was unknown at the time. Consequently, the methods used to measure dispersant components had to be developed under crisis conditions,[45] and very few studies could be conducted during this dynamic situation.[46]

Conducting strategic and comprehensive scientific inquiry, including hypothesis testing, is not possible during an intense crisis because scientists are often burdened with answering fragmented 'questions of the day' and must frantically analyze specific samples to allay public concerns. During any environmental crisis, we should apply standardized and established methods rather than frantically develop new technology. In these situations, time is of the essence and validated methods will generate confidence.[47] Hence it is imperative that there be a robust understanding of the ecosystem status *prior to and in between* inevitable environmental disasters.

2. *What Do We Know About the Toxicity of Petroleum Emulsified with Chemical Dispersants?*

Presently, there is no published data on the impact of spilled oil from the DWH incident on the larvae of bluefin tuna, a protected and commercially desirable species that would have been spawning at the time of the DWH spill. Nonetheless, earlier results from the NWFSC scientists demonstrate that herring larvae exhibited sub-lethal (i.e.,cardiac impairment) and lethal effects in San Francisco bay after Bunker fuel oil was spilled from Cosco Busan in 2007.[48] It is known from

44. *Nat'l Comm'n on the BP Deepwater Horizon Oil Spill & Offshore Drilling*, *supra* note 4.

45. Ylitalo et al., *supra* note 38.

46. Richard S. Judson et al., *Analysis of Eight Oil Spill Dispersants using Rapid In Vitro Tests for Endocrine and Other Biological Activity,* 44 ENVTL. SCI. TECH., 5971, (2010).

47. Varanasi, s*upra* note 4.

48. John P. Incardona et al., *Potent Phototoxicity of Marine Bunker Oil to*

many literature reports that organisms are generally more sensitive in their early life stages than adults to PACs at very low concentrations.[49] Recent findings from areas impacted by the DWH disaster show that there may be a strong synergistic effect of oil components mixed with dispersant on planktonic organisms as measured by a standard toxic test called LD50, which determines the concentration of toxicant that causes fifty percent of test organisms to die within forty-eight to ninety hours.[50] The authors reported that rotofirs (zooplankton) were forty times more sensitive to oil when it was mixed with the chemical dispersant.[51] If methods to assess the uptake and impact of Corexit and toxicity of emulsified oil had been funded and developed prior to the DWH incident, application of the dispersant on such a large scale might have proceeded more cautiously.

III. THE CONSEQUENCES OF INSUFFICIENT BASELINE DATA PRIOR TO AN ENVIRONMENTAL DISASTER

As stated by Kathryn Mangerick of the Environmental Law Institute:

> Under current law, responsible parties are only liable for known injuries to natural resources. But many injuries will not be known because baseline conditions may not be knowable once a spill has occurred. Therefore, updating the Oil Pollution Act (OPA) should begin with a mandate to conduct temporally and spatially explicit ecosystem assessments in ocean and coastal waters in order to establish the baseline upon

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Translucent Herring Embryos After Prolonged Weathering, 7 PLOS ONE e30116 (2012), *available at* http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0030116; John P. Incardona et al., *Unexpectedly High Mortality in Pacific Herring Embryos Exposed to the 2007 Cosco Busan Oil Spill*, 109 PROC NAT'L. ACAD. SCI. E51-E58 (2012), *available at* http://www.pnas.org/content/109/2/E51.

49. Incardona*, Unexpectedly High Mortality in Pacific Herring Embryos Exposed to the 2007 Cosco Busan Oil Spill in San Francisco Bay*, *supra* note 48; Jee-Hyun Jung et al*., Geologically Distinct Crude Oils Cause a Common Cardio-toxicity Syndrome in Developing Zebrafish*, 19 CHEMOSPHERE 1146 (2013); John P. Incardona et al., *Exxon Valdez to Deepwater Horizon: Comparable Toxicity of Both Crute Oils to Fish Early Life Stages*, 142–43 AQUATIC TOXICOLOGY 303 (2013).

50. Roberto Rico-Martinez et al*., Synergistic Toxicity of Macondo Crude Oil and Dispersant Corexit 9500A® to the Brachionus Plicatilis Species Complex (Rotifera),* 173 ENVTL. POLLUTION 5 (2013).

51. *Id.*

> which to assess injury. Such ecosystem assessments could be integrated into contingency plans to inform spill response and cleanup efforts. They could also inform broader ocean development and planning efforts.[52]

Despite such clarion calls made after each major disaster, the most glaring deficiency during environmental catastrophes (e.g., EVOS, Hurricane Katrina or DWH) is the lack of standardized and robust baseline information about the state of the environment prior to the disaster. This lack of pre-storm or pre-spill data on levels of chemical contaminants in seafood, the water column, or bottom sediment from the affected regions severely hampers our ability to determine what additional impact was caused by the spill. In the past thirty years, there have been attempts to mount the systematic nationwide monitoring of fish and shellfish to determine baseline levels of chemical contaminants and associated diseases, such as EPA's E-MAP and NOAA's Benthic Surveilance and Mussel Watch programs.[53] But as mentioned above, funding for sustained long-term monitoring is virtually non-existent. Most programs are terminated after several years and those surviving[54] face severe budget constraints.

Soon after the DWH incident, scientists and lawyers alike proposed that the OPA should be modified to mandate baseline ecosystem assessments in advance of oil and gas activities.[55] But this deficiency was well-known prior to the DWH spill by industry and government insiders. Collecting baseline data should be the standard; elimination of ignorance need not await an act of Congress. However, lack of appropriated funding is often a limiting factor. Instead of responding to

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52. Kathryn Mengerink, *Need to know Ecosystem Status Prior to a Spill*, in *Deepwater Horizon: Updating OPA*, *supra* note 6, at 49.

53. Monitoring of bottom fish under OCSEAP program was discontinued and there was only one station (Cook Inlet) in Alaska where bottom fish and sediment were analyzed annually under NOAA's national monitoring program, Benthic Surveillance (1984–1994). This baseline information from even one station prior to EVOS was very useful to assess the change in the level of oil contamination in sediment and fish after EVOS. No such prior baseline information has been available for sites impacted by gulf storms in 2006 and the DWH spill 2010.

54. One such program is NOAA's Mussel Watch program, *see* NOAA.gov, Chemical Contaminants in Oysters and Mussels, http://stateofthecoast.noaa.gov/musselwatch/welcome.html (last visited Nov. 23, 2013).

55. Varanasi, *supra* note 4; *Deepwater Horizon: Updating OPA*, *supra* note 6; Donald Boesch, *Deep-water drilling remains a risky business*, 484 NATURE 289 (2012).

incidents by modifying laws after a disaster, we should be ahead of the curve and anticipate these issues. At a minimum, targeted baseline monitoring should be conducted to determine levels of contaminants, as well as the abundance and health of organisms.[56]

A. *Proposal for Funding Strategies and Models*

The nation's budget for science and research is dwindling. Under such a budget climate, policymakers are not likely to launch a nation-wide sustainable effort to collect baseline data on level of contamination or status of ecosystem health parameters. We need a dramatically different approach to generate revenue for targeted baseline monitoring wherever permits are requested for drilling for oil and gas[57] or for any other installations such as wind or wave turbines in public waters. Provision for funding ecosystem research and assessment should be part of any amendments to federal laws and rules (e.g., OPA, Coastal Zone Management Act) that oversee alterations to our coasts and oceans. Significant fees should be collected, and these moneys should be contributed to a national trust fund which would be managed independently.[58] Funding should be made available to scientists from all sectors for the purpose of investigating the potential impacts of an oil spill or other anthropogenic disasters on both human health and safety and ocean life before a crisis happens. Scenario building and development of a long-term strategy of remediation were the disaster to happen should be studied and debated in the open. Such strategic and thoughtful frontloading of science would enable us to better protect the public and marine life by making environmental decisions more wisely.

IV. FRONTLOADING OF SCIENTIFIC INFORMATION WITHIN A REGULATORY FRAMEWORK

The story I narrate in this section was initiated by an unusual partnership of scientists, attorneys, and regional managers in the Northwest region of NOAA just before I

56. Varanasi, *supra* note 4.
57. *Deepwater Horizon: Updating OPA*, *supra* note 6; Bratspies, *supra* note 6.
58. Varanasi, *supra* note 4; *see also* Mengerink, *supra* note 52.

became the science and research director of NWFSC in 1994. My role was to support and shepherd this novel venture by ensuring that the management and policy decisions that influenced Pacific Northwest salmon were supported by a robust, timely and practical scientific underpinning, and that scientists were supported by adequate funding.

A. *Case Study 2: Status Reviews and Recovery Planning for Pacific Salmon*

Salmon play a major role in aquatic and terrestrial ecosystems. They are part of Native American spiritual and cultural identity, support the Pacific Northwest, and play a significant role in the nation's economy. For several decades, scientists in the Pacific Northwest had been frontloading science and technology to help them observe and understand this amazing assemblage of species and document wild salmon populations' steady declines.[59] This scientific information and these concepts have served as the foundation for making good conservation management decisions during the listing and recovery planning processes. The first Pacific Northwest petitions to list several populations of salmon under Endangered Species Act (ESA)[60] were submitted to NMFS in the early 1990s,[61] but at the time nobody knew how to evaluate

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59. F. Utter et al,. *Genetic Population Structure of Chinook Salmon in the Pacific Northwest*, 87 FISHERY BULLETIN 239 (1989); Robin S. Waples et al., *Genetic Approaches to the Management of Pacific Salmon.* 15 FISHERIES 19, (1990); JEFF J. HARD ET AL., NOAA, TECHNICAL MEMORANDUM NMFS-NWFSC-2 PACIFIC SALMON AND ARTIFICIAL PROPAGATION UNDER THE ENDANGERED SPECIES ACT (1992); Thomas A. Flagg et al., *Captive Broodstocks for Recovery of Snake River Sockeye Salmon.* AMERICAN FISHERIES SOCIETY SYMPOSIUM 15, USES AND EFFECTS OF CULTURED FISHES IN AQUATIC ECOSYSTEMS 81 (Harold L. Schramm Jr. and Robert G. Piper eds., 1995); Stephen Achord et al., *Use of Passive Integrated Transponder (PIT) Tags to Monitor Migration of Snake River Chinook Salmon Smolts*, 16 N. AM. J. FISH. MGMT. 302 (1996); Charles A. Simenstad, *The role of Puget Sound and Washington estuaries in the life history of Pacific salmon: An unappreciated function*, in ESTUARINE COMPARISONS (Victor S. Kennedy ed., 1982); NAT'L RESEARCH COUNCIL, UPSTREAM: SALMON AND SOCIETY IN THE PACIFIC NORTHWEST (1996); JAMES A. LICHATOWICH, SALMON WITHOUT WATERS: A HISTORY OF THE PACIFIC SALMON CRISIS (1999).

60. The ESA defines an endangered species as one that is "in danger of extinction" and a threatened species as one that is "[l]ikely to become an endangered species in the foreseeable future." 16 U.S.C. §§ 1532(6), (20) (2012). According to the Act, listing determinations are based "solely on best scientific and commercial data available." 16 U.S.C. § 1533(b)(1)(A) (2012).

61. *See, e.g.,* Notice of Status Review for Sockeye Salmon (Oncorhynchus nerka), 55 Fed. Reg. 13,181 (April 9, 1990), Petitions To List Snake River Spring, Summer, and

the ESA status of salmon. Such knowledge would of course be necessary in determining how to best protect and restore population structure.[62] At the request of NMFS managers, Robin Waples[63] of the NWFSC crafted an innovative strategy to identify major segments—Evolutionarily Significant Units (ESUs)[64] of genetic diversity—the building blocks of diversity for the species.

1. *Conventional Protocol for Evaluating the Status of a Species Under ESA Petitions*

The conventional protocol for a listing under the ESA followed by both NMFS and the U.S. Fish and Wildlife Service (USFWS) is as follows: First, the petition to protect a population of a marine or anadromous (e.g., salmon that are born in freshwater, transition to saltwater and return to fresh water to reproduce) species under the ESA is filed by a third party with NMFS. If the petition is accepted based on its merits, the agency's regional managers have one year from the receipt of petition to assess the status of the petitioned species with the help of scientists. Managers use the scientific assessment to make a recommendation to the Secretary of the Department of Commerce. The Secretary, with the help and advice of the Department's General Counsel, designates the species or population as threatened or endangered under ESA or determines that listing is not warranted.[65] Between 1992–1994, the NWFSC conducted several additional status reviews triggered by petitions in a conventional manner, but it soon became apparent that it would be much more rigorous and efficient to conduct comprehensive species level (i.e., chinook,

Fail Chinook Salmon, and Lower Columbia River Coho Salmon, 55 Fed. Reg. 36,342 (Sept. 11, 1990).

62. Robin S. Waples, *Pacific Salmon,* Oncorhynchus *spp., and the Definition of "Species" Under the Endangered Species Act*, 53 MAR. FISH. REV. 11 (1991).

63. Robin S. Waples*, Evolutionarily Significant Units and the Conservation of Biological Diversity Under the Endangered Species Act, in* AMERICAN FISHERIES SOCIETY SYMPOSIUM 17, EVOLUTION AND THE AQUATIC ECOSYSTEM: DEFINING UNIQUE UNITS IN POPULATION CONSERVATION 8 (1995).

64. Policy regarding the recognition of distinct vertebrate population segments under the Endangered Species Act, 61 Fed. Reg. 4,722 (Feb. 7, 1996).

65. *Listing Under the Endangered Species Act (ESA)*, NOAA FISHERIES, http://www.nmfs.noaa.gov/pr/listing/ (last visited Nov. 23, 2013); *Listing and Critical Habitat: Petition Process*, U.S. FISH & WILDLIFE SERVICE, http://www.fws.gov/endangered/what-we-do/listing-petition-process.html (last visited Nov. 23, 2013).

coho, sockeye, chum, pink) reviews that encompassed the full geographic range of populations that spawn in watersheds of the western U.S.

2. *Frontloading Science by Launching Coast Wide Status Reviews of Pacific Salmon*

NMFS scientists proposed, and agency managers and attorneys agreed, to conduct coast-wide reviews for each west coast salmon species systematically rather than wait for individual petitions to arrive. NMFS delineated this new process in the Federal Register in 1994. It took a large team of scientists until the end of the decade to complete the task.[66] This was a huge proactive (or anticipatory) undertaking by the scientists that required significant upfront funding. With the strategic support of NMFS administrators and managers on

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66. Anatomy of Status Reviews: Each status review comprises of one or more ESUs of salmon species. It begins with an open process aimed at getting together everyone who has an interest in resource conservation to discuss the best science and information available. NMFS establishes a Biological Review Team (BRT) of experts (consisting of federal scientists with variety of expertise in salmon biology, ecology, genetics, and fishery biology). The BRT is charged with evaluating the existing information on genetic data as well as ecological and life history data to determine which set of populations constitute Evolutionarily Significant Units (ESUs), identifying the threats to the individual ESUs, and then assessing the risk of extinction for each ESU from the identified threats. During the process, there are several interim steps to ensure that all pertinent data are collected and used in these analyses as data for salmon species are collected by States, Tribes as well as federal scientists. Scientific conclusions of BRT are then evaluated along with any existing conservation measures by resource managers at the NMFS Regional Offices to determine if an ESU is to be listed or not. If a species is listed as threatened or endangered, then the recovery planning process begins. *See* Initiation of Status Reviews for Pink Salmon, Chum Salmon, Chinook Salmon, and Sea-Run Cutthroat Trout Populations in Washington, Oregon, Idaho, and California, 59 Fed. Reg. 46,808 (Sept. 12, 1994); LAURIE A. WIETKAMP, ET AL., U.S. DEPT. OF COMMER., NOAA TECH. MEMO. NMFS-NWFSC-24, STATUS REVIEW OF COHO SALMON FROM WASHINGTON, OREGON, AND CALIFORNIA. U.S. DEPT. OF COMMERCE 258 (1995); FRANK W. WAKNITZ, ET AL., U.S. DEPT. OF COMMER., NOAA TECH. MEMO., NMFS-NWFSC-22, STATUS REVIEW FOR MID-COLUMBIA RIVER SUMMER CHINOOK SALMON (1995); PEGGY J. BUSBY ET AL., U.S. DEPT. OF COMMER., NOAA TECH. MEMO., NMFS-NWFSC-27, STATUS REVIEW OF WEST COAST STEELHEAD FROM WASHINGTON, IDAHO, OREGON, AND CALIFORNIA (1996); Jeff J. Hard et al.,*supra* note 59*;* R.G. GUSTAFSON ET AL., U.S. DEPT. OF COMMER., NOAA TECHNICAL MEMO., NMFS-NWFSC-33STATUS REVIEW OF SOCKEYE SALMON FROM WASHINGTON AND OREGON (1997); JAMES M. MYERS ET AL., U.S. DEPT. OF COMMER., NOAA TECH. MEMO. NMFS-NWFSC-35, STATUS REVIEW OF CHINOOK SALMON FROM WASHINGTON, IDAHO, OREGON, AND CALIFORNIA (1998); ORLAY W. JOHNSON ET AL., U.S. DEPT. OF COMMER., NOAA TECHNICAL MEMO. NMFS-NWFSC-37, STATUS REVIEW OF COASTAL CUTTHROAT TROUT FROM WASHINGTON, OREGON, AND CALIFORNIA (1999).

the west coast, additional funding was invested into the frontloading of scientific information. This enabled them to identify the presence of fifty-two ESUs throughout the western region of the U.S.; twenty-seven of these ESUs were eventually listed for protection under ESA.[67] This case study (Figure 4) demonstrates that the effective frontloading of science can occur only with the understanding and support of agency managers and policy leaders.[68]

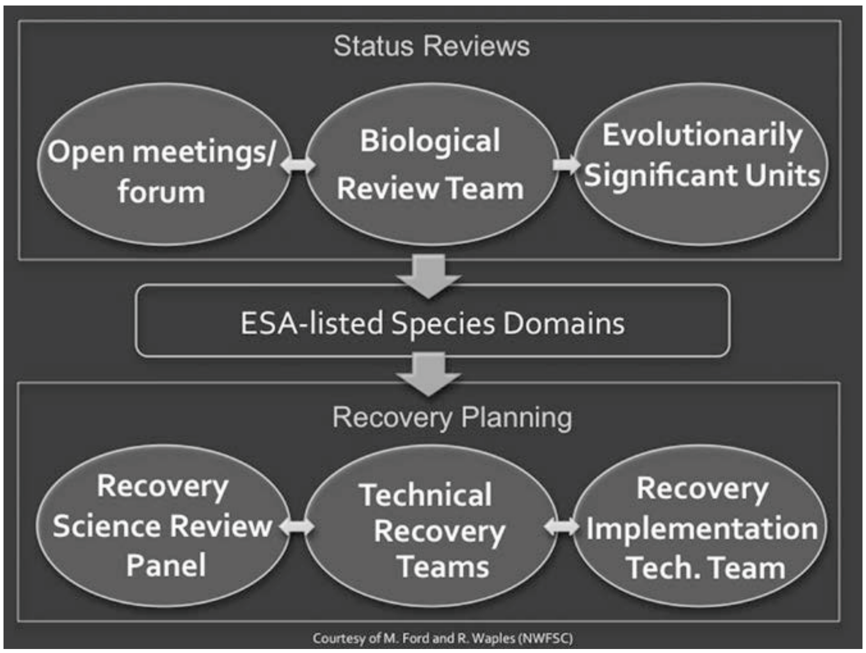

Figure 4. Depiction of processes established by NMFS for collaborative assessment of status and recovery of marine and anadromous species

3. *Recovery Planning (Required under ESA)*

Once listed under the ESA, the responsible federal agency must develop a recovery plan to describe the actions needed to improve the population's status to a level that warrants de-listing under the ESA. Declining salmon populations are the result of many factors. These include economic development and resource extraction involving aggressive harvest practices,

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67. U.S. DEPT. OF COMMER., NOAA TECH. MEMO., NMFS-NWFSC-66, UPDATED STATUS OF FEDERALLY LISTED ESUS OF WEST COAST SALMON AND STEELHEAD (Thomas P. Good et al. eds., 2005).

68. See Figure 4.

habitat loss and degradation, hatchery production, dams, pollution and climate change. To reverse this pattern, it is critical that comprehensive, focused recovery efforts take place throughout the region.[69] Given the scope and geographic range of Pacific salmon, NMFS scientists, managers, and attorneys agreed that it was critical to develop robust scientific information to underpin recovery efforts. Thus, on the science and research front, we expanded the NWFSC salmon program to study the entire complex life cycle (from egg to adult) and various habitat requirements.[70] Customarily, the managers, rather than the scientists, lead recovery planning in NMFS and other agencies. In this case, however, NMFS designated the NWFSC as the lead entity for the effort. Thus, this approach to recovery planning was entirely novel in that an NFMS science center led the first phase of recovery planning in the region rather than the managers.

a. *Establishment of Coast-Wide Technical Recovery Teams*

NMFS created Technical Recovery Teams (TRTs) as the centerpiece of the first phase of ESA recovery planning. The major goals were to a) identify fine-scale population structure, and b) develop biologically-based recovery criteria that are consistent with long-term viability (and hence delisting). These teams, notably the Puget Sound TRT, worked independently but communicated closely with NMFS managers and regional policy teams to ensure that their scientific analyses were conducted and reported in ways that were comprehensible to

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69. PAUL M. MCELHANEY ET AL, U.S. DEPT. OF COMMER., NOAA TECHNICAL MEMORANDUM NMFS-NWFSC-42, VIABLE SALMONID POPULATIONS AND THE RECOVERY OF EVOLUTIONARY SIGNIFICANT UNITS (2000).

70. Beechie, *An Approach to Restoring Salmonid Habitat-Forming Processes in Pacific Northwest Watersheds*, *supra* note 10; Beechie, *Process-Based Principles for Restoring River Ecosystems*, *supra* note 10; Beechie, *Restoring Rivers in the 21st Century: Science Challenges in a Management Context*, *supra* note 10; Battin et al., *supra* note 10; Robin S. Waples et al., *Characterizing Diversity in Salmon from the Pacific Northwest*, 59 J. FISH BIOLOGY SUPP. A 1 (2001); DONALD L. BOTTOM ET AL., U.S. DEP. OF COMMER., NOAA TECHNICAL MEMO. NMFS-NWFSC, SALMON AT RIVER'S END: THE ROLE OF THE ESTUARY IN DECLINE AND RECOVERY OF COLUMBIA RIVER SALMON, (2005); Robin S. Waples et al., *Evolutionary History of Pacific Salmon in Dynamic Environments*, 1 EVOLUTIONARY APPLICATIONS 189 (2008); John G. Williams et al., *Potential for Anthropogenic Disturbances to Influence Evolutionary Change in the Life History of a Threatened Salmonid*, 1 EVOLUTIONARY APPLICATIONS 271 (2008); Michelle M. McClure et al., *Evolutionary Consequences of Habitat Loss for Pacific Anadromous Salmonids,* 1 EVOLUTIONARY APPLICATIONS 300 (2008).

the public and useful to policy makers.[71] The TRT format and Shared Strategy organization[72] allowed policy makers to experience real-time interactions with the scientists[73] and to make use of scientific information[74] in the most optimal way.[75]

b. *Implementation Teams Led by Regional Managers*

The NMFS regional offices and the West Coast science centers agreed that after each TRT completes its function, a Recovery Implementation Team (RIT) would replace it. The RIT has multi-agency, multi-disciplinary experts that provide scientific support to regional managers responsible for implementing the recovery plans. Effectiveness of this novel process, namely RIT, will need to be evaluated in due time as this is 'work in progress.'

The RIT identifies suites of actions that are likely to achieve population and ESU recovery goals. The RIT also addresses a series of questions that span the science-policy interface. Examples of these science-policy questions may include: What are acceptable ecological risk levels for ESUs?; How do they vary with economic or social costs for recovery?; Which alternatives for a biologically "recovered" ESU are most consistent with policy objectives? Such questions are important in science and policy, and an increased understanding of both can improve the chance for successful recovery planning.

71. PUGET SOUND TECHNICAL RECOVERY TEAM AND SHARED STRATEGY STAFF GROUP, SHARED STRATEGY FOR PUGET SOUND, INTEGRATED RECOVERY PLANNING FOR LISTED SALMON: TECHNICAL GUIDANCE FOR WATERSHED GROUPS IN PUGET SOUND (2002).

72. Shared Strategy for Puget Sound takes action to protect salmon through a collaborative effort, initiated by, federal, state, tribal and local government, along with various industries, to develop a long-term plan for salmon recovery in Puget Sound. *See Puget Sound Recovery Plan*, SHARED STRATEGIES FOR PUGET SOUND, http://www.sharedsalmonstrategy.org/plan/index.htm.

73. Edward P. Weber et al., *Civic Science in Salmon Recovery Planning in Puget Sound*, 38 Policy Studies Journal 235 (2010).

74. Tom P. Good et al., *Recovery Planning for Endangered Species Act-listed Pacific Salmon: Using Science to Inform Goals and Strategies,* 32 Fisheries 426 (2007); Tom P. Good et al., *Incorporating Catastrophic Risk Assessments into Setting Conservation Goals for Pacific Salmon*, 18 Ecological Applications 246 (2008); Shalin D. Busch et al., *A Practical Comparison of Viability Models Used for Management of Endangered and Threatened Anadromous Pacific Salmonids*. 33 N. Am. Journal of Fisheries Mgmt. 1,125 (2013).

75. See Figure 4.

This case study demonstrates that early involvement of scientists with regulators (agency managers and attorneys) and policy makers in broader ocean development and planning efforts will give the planet and its inhabitants, including humans, a better chance of long-term survival and success. Yet the need for sustained funding and the long-term nature of the endeavor presents constant challenges in maintaining the attention, focus and support of policy makers.

V. CONCLUSION

I would like to conclude with a few thoughts that address the necessity of frontloading science in anticipation of environmental change and the principles and properties of sound science:

- The scientific framework must be holistic even when in-depth research needs to focus on fragments or sections within the framework. Conducting scientific research against the backdrop of a holistic framework allows for better incorporation of scientific information into a legal and policy framework.
- Prominence must be given to good data, and we must resist the temptation to use poor data just because it is available. In the absence of quality data, we must clarify our analytical assumptions.
- Long-term monitoring and evaluation of effectiveness are necessary to ensure that the application of science has the intended effects and to allow for the generation of valuable data.
- The organizational, managerial, and legal framework must support rigorous, independent science. This includes adequate and timely funding that allows for the frontloading of science.
- Science by its nature is not conducted by consensus, yet certain collaborative processes are necessary to ensure transparency, to solicit input from diverse groups, and to increase the chances for general acceptance.
- Scientists must take the initiative in directing and guiding science-based processes that provide the underpinning for the management and conservation of natural resources. In short, science must lead as well as

serve.

- Lastly, and perhaps most importantly, the nation's laws and policies need to be amended[76] so that frontloading of holistic science becomes the norm—rather than a rare occurrence—in anticipation of environmental change. Such a shift should be accompanied by a mandate that requires sustained funding to conduct temporally and spatially explicit ecosystem assessments in ocean and coastal waters in order to establish the baseline upon which to assess injury.

76. Mengerink, *supra* note 52; Boesch, *supra* note 55.