VOLUME 76
Number 1
March 1986

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly
at Washington, D.C.

WASHINGTON ACADEMY OF SCIENCES 1898

PROCEEDINGS OF THE CHARLES A. LINDBERGH SYMPOSIUM

(Contents continued)

Washington Academy of Sciences

Founded in 1898

ACADEMY OFFICE

1101 N. Highland St.
Arlington, Va. 22201
Telephone: (703) 276-9254

The Journal

This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Board of Managers; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the September issue contains a directory of the Academy membership.

Subscription Rates

Members, fellows, and patrons in good standing receive the *Journal* without charge. Subscriptions are available on a calendar year basis only, payable in advance. Payment must be made in U.S. currency at the following rates:

U.S. and Canada . . .	$19.00
Foreign.	22.00
Single Copy Price . . .	7.50

Single-copy price for Vol. 66, No. 1 (March, 1976) is $7.50.

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Published quarterly in March, June, September, and December of each year by the Washington Academy of Sciences, 1101 N. Highland St., Arlington, Va. 22201. Second class postage paid at Arlington, Va. and additional mailing offices.

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Dedication

What kind of man would live where there is no daring? I don't believe in taking foolish chances, but nothing can be accomplished without taking any chance at all.

—Charles Augustus Lindbergh

This volume is respectfully dedicated to the crew of the Space Shuttle, Challenger, men and women who accepted the risks of exploration on behalf of all mankind.

IN MEMORIAM

Crew of Shuttle Mission 51-L, Challenger, January 28, 1986

Francis R. (Dick) Scobee, spacecraft commander. Born May 19, 1939, Cle Elum, Washington. He became a NASA astronaut in 1978.

Michael J. Smith, pilot. Born April 30, 1945, Beaufort, North Carolina. He became a NASA astronaut in 1980.

Judith A. Resnik, mission specialist. Born April 15, 1949, Akron, Ohio. She became a NASA astronaut in 1978.

Ronald E. McNair, mission specialist. Born October 21, 1950, in Lake City, South Carolina. He became a NASA astronaut in 1978.

Ellison S. Onizuka, mission specialist. Born June 24, 1946, Kealakekua, Kona, Hawaii. He became a NASA astronaut in 1978.

Gregory B. Jarvis, payload specialist. Born August 24, 1944, Detroit. He was selected as a payload specialist from Hughes Aircraft Corp. in 1984.

S. Christa Corrigan McAuliffe, teacher. Born September 2, 1948, Boston, Massachusetts. She was selected as the primary candidate for the Shuttle Teacher in Space project in July 1985.

The crew of mission 51-L was lost shortly after launch aboard the Shuttle Challenger from NASA's Kennedy Space Center as a result of an in-flight explosion.

Editor's Note

Dr. Richard D. Gilson*

Guest Editor

This volume of the Journal of the Washington Academy of Sciences is devoted to a series of invited presentations given at The Charles A. Lindbergh Symposium, held at the Walt Disney World Conference Center, Lake Buena Vista, Florida, February 2–4, 1986. The Symposium was sponsored by The Charles A. Lindbergh Fund, Inc., whose purpose and activities are described by the Chairman of the Board, the Hon. Elmer L. Anderson, Chairman of the H. B. Fuller Company. A special message from the Lindbergh family is given by Reeve Lindbergh Brown, Vice President of the Charles A. Lindbergh Fund.

The Symposium Proceedings represent the Fund's first endeavor to publish the views and current research in what the Fund members simply refers to as the "balance"—between technological growth and preservation of our human and natural environment. Four points of "balance" were addressed in the following sessions:

AEROSPACE/ENERGY/ENVIRONMENT
Dr. Paul B. MacCready, Session Chairperson
(Chairman of Board, AeroVironment, Inc.)

THE TOXIC WASTE DILEMMA: CURRENT STRATEGIES, FUTURE ISSUES
William K. Reilly, Session Chairperson
(President, The Conservation Foundation)

BIOLOGICAL DIVERSITY AND DEVELOPMENT
Dr. Thomas E. Lovejoy, Session Chairperson
(Vice President-Science, World Wildlife Fund)

SEA AND SPACE: FRONTIERS FOR EXPLORATION
Dr. Sylvia A. Earle, Session Chairperson
(Vice President, Deep Ocean Technology Inc.)

In the Fund's nine year history, it has seeded new research and has highlighted lifelong efforts for grant recipients and honorary award winners, respectively, but it has yet to provide a publication vehicle for that work. These papers represent two new endeavors by the Fund. First, to create a scientific symposium "mid-year" to the traditional grants and awards dinner held in May to commemorate the anniversary of Lindbergh's May 20–21, 1927 solo trans-Atlantic flight; and second, to publish the views of internationally recognized scientific experts at mid-career in their respective fields. The intent

*Visiting Professor, University of Central Florida.

of the latter is to present current exemplary research, pose questions to be addressed in future global efforts, and to create a positive, non-confrontational format for influencing public policy.

The Washington Academy of Sciences has kindly agreed to create a special edition of their Journal at the suggestion of Proceedings Associate Editor, Dr. Robert Sweezy, and with the support of Dr. Robert Evans, also an Associate Editor of the Proceedings. The timing of this volume is intended to coincide with the May, 1986 Lindbergh Awards Presentation Ceremonies to be held in Washington, D.C.

The Fund's Board of Directors extends its gratitude to Gloria S. Perkins, Grants and Awards Administrator and Symposium Coordinator, for solicitation of papers from the twenty Symposium Presenters, and to Lisa Gray, Managing Editor of the Journal of the Washington Academy of Sciences, for her marathon efforts shaping this collection of work into the Academy's official format.

The Charles A. Lindbergh Fund also wishes to express great appreciation to the Lindbergh Symposium Central Florida Host Committee, whose efforts contributed so much to state-wide participation in the three days of events. Co-Chairmen of the Committee are:

Major General W. E. "Joe" Potter,
U.S. Army (Ret.)
Member
Orlando Aviation Authority

Raymer F. Maguire, Jr.
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Hope Strong, Jr.
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Dr. Charles N. Millican
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University of Central Florida

Tom Heyward, Jr.
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Greater Orlando Chamber of Commerce

The Lindbergh Fund extends its thanks to the following for their generous assistance and contributions to the Symposium:

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University of Central Florida
Valencia Community College
Walt Disney World/Epcot Center

Background: *The Charles A. Lindbergh Fund*

Elmer L. Andersen

Chairman of the Board

The Charles A. Lindbergh Fund was established in 1977 by friends of Charles Lindbergh who were members of the Explorers Club, New York City, to honor the legacy of the late, famed aviator and advance his philosophy that true progress for mankind requires a balance between technological advancement and preservation of the environment and the quality of life. Each year since 1978, the Fund has made grants to researchers whose proposed projects offer excellent potential to contribute to such a balance. The honorary Lindbergh Award has also been presented by the Fund each year to one individual whose lifetime's work has made an extraordinary contribution in this critical area.

The Lindbergh Fund is proud to have sponsored the Lindbergh Symposium, which we feel made a significant contribution to "the search for balance." And we are further pleased that, through this publication, the proceedings of the symposium are being made available to an even wider audience.

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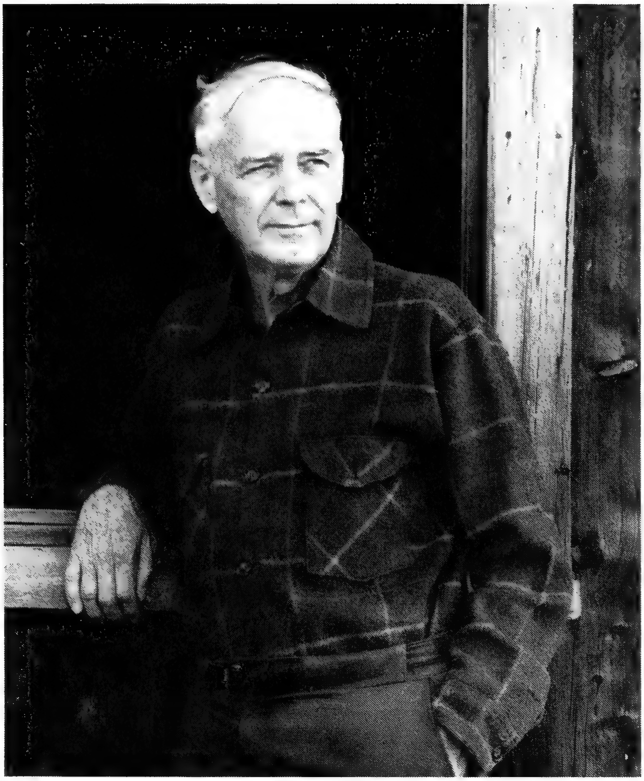

Photo by Richard W. Brown

A Lindbergh Family Remembrance

Reeve Lindbergh Brown
Vice President, Charles A. Lindbergh Fund

As a director of the Charles A. Lindbergh Fund and a member of the Lindbergh family, I felt doubly privileged to participate in the Lindbergh Symposium this February. I was gratified, as a director of the Fund, to hear our organization's guiding philosophy so eloquently expressed by our keynote speaker, David McCullough,* and to witness the enthusiasm and expertise with which our second speaker, aerospace and underwater expert Sir John Rawlins, addressed the symposium's theme: "Environment and Technology: A Search for Balance." I was deeply appreciative of the contributions of our four panel leaders and the distinguished authorities who presented papers in each area of concern. It was very clear to me that the Lindbergh Fund had succeeded in bringing together an extraordinary group of people, each committed to the concept of balance as envisioned by Charles Lindbergh.

As a member of the Lindbergh family, it was tremendously satisfying to realize on February 4, 1986, the 84th anniversary of my father's birth, just what a gift to his memory the Lindbergh Symposium represented. In the years since his death, my father has received innumerable tributes, of many kinds, for the work he accomplished during his lifetime. I can think of no tribute, however, that would please him more than the knowledge that work is being carried out in his name right now, by those who wish to carry his vision of balance into the future.

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*Presentation not available for publication at this time.

"Upstairs/Downstairs"*

Surgeon Vice-Admiral Sir John Rawlins

Chairman of the Board, Deep Ocean Engineering, Inc.

Summary

This paper draws attention to some common physiological and human factors problems in diving and submarine operations on one hand, and in aviation and space operations on the other, and illustrates the application of underwater techniques to solve aviation problems and visa versa. It is largely a personal account of work carried out by the author and his colleagues during 33 years of service in the medical branch of the Royal Navy.

Introduction

When I tell people that I switched from aviation medicine to underwater medicine the usual comment is, "Well, it's all a matter of pressure, isn't it?" Actually, it's a bit more than that.

The problem of hypoxia in flight was first starkly demonstrated by the deaths of the French balloonists, Sivel and Croce Spinelli, during their balloon ascent to 20,200 ft in 1875, and here hypoxia was a direct result of the diminished atmospheric pressure. In diving, there is always an *increase* in ambient pressure, but hypoxia is much more common amongst divers than amongst aviators.

Particularly at risk are breath-hold divers such as the Ama, the famous diving women of Korea and Japan, and snorkel divers. Experienced breath-hold divers, however, can go to astonishing depths. Jaques Mayol, at the age of 35, baffled physiologists by making a world record breath-hold dive to 97 m. Last year, at the age of 55, he extended the record to 105 m!

Military divers and commercial divers, who use artificial mixtures of oxygen and nitrogen, or oxygen and helium, are also liable to hypoxia if the oxygen partial pressure in the breathing mixture is allowed, for one reason or another, to fall too low. So here we have hypoxia, a common hazard for both divers and aviators, often, but not necessarily, related to a fall in the ambient pressure.

*A more complete version of this paper was published as: Rawlins, J. 1985. "Upstairs/Downstairs—Interactions Between Human Factors Aspects of Operating in Hypobaric and Hyperbaric Environments." *Underwater Technology*. 11 (1): 22–27.

Hypoxia and Decompression

In 1920, Professor J. S. Haldane, whose sterling work on the first and second Admiralty Deep Diving Committees established the principal of decompression employed by today's commercial and sport divers, predicted that the "bends" that plagued divers and caisson workers could occur in high altitude flight. The RAF medical hierarchy, however, did not believe him on the grounds that the pressure changes in flight were too small, and in any case the aviator always returned to maximum pressure, that is to say, ground level, which for the diver represents minimum pressure. Hence, although much work was done between Wars on hypoxia and means to prevent it, no work was done in England on what is now universally known as "decompression sickness."

The latter term was coined by Dr. (now Sir Bryan) Matthews, Head of the Royal Air Force Physiological Laboratory throughout World War II. He and his colleagues set about proving to the Royal Air Force that high altitude flight could induce decompression sickness by exposing themselves repeatedly to low pressures in the decompression chamber at Farnborough. In a series of horrendous experiments which would never be permitted today, they experienced a whole range of symptoms of decompression sickness. It is remarkable that no one died or suffered permanent paralysis—such cases have happened since—but they proved their point. It was many years, however, before the threat of high altitude decompression sickness was finally overcome by the development of reliable pressure cabins.

In view of the official RAF attitude to decompression sickness, it may seem surprising that a pressure suit was designed by the diving company Siebe Gorman in 1934 for an American balloonist, which was subsequently used by Flight Lieutenant Adams in a flight to the record altitude of 54,000 ft in 1937. Presumably the purpose of the suit was to provide an adequate partial pressure of oxygen in the lungs of the pilot, rather than to protect him against decompression sickness, although of course it did this as well.

It is said that Siebe Gorman easily achieved the suit by adapting a self-contained diving dress. This was no doubt true in terms of material and method of fabrication, but it should be remembered that the Siebe Gorman diving dress was flexible, and not designed to cope with a pressure differential. The suit worn by Flight Lieutenant Adams was more comparable in principle to the armoured diving dress, *Jim*, which is designed to isolate its operator from ambient pressure. At the other end of the pressure spectrum is the lunar landing suit worn by Neil Armstrong.

When the Royal Navy invited me to rejoin in 1951, part of the inducement was the promise of an immediate posting to the Royal Air Force Institute of Aviation Medicine where, they said, there would be workshop facilities where I could build diving apparatus to my heart's content. The bait was irresistible and I swallowed it hook, line, and sinker. I never dreamed that I would have occasion to use my knowledge and love of diving in pursuit of official aviation medicine objectives.

Underwater Escape

The pages of my scrap book revive memories of two incidents that changed the course of my life and had profound consequences concerning certain aspects of aviation safety. One concerns the first Scimitar aircraft to land on an aircraft carrier, an apparently perfect landing with subsequent roll up on the deck—and over the side. The pilot went down with the plane. The other was an accident when another Naval aircraft crashed into the sea from a carrier. The pilot, Lt. Bruce McFarlane, said that when his aircraft hit the sea, he was paralyzed with fright and could only move his right arm. With it he pulled the canopy jettison lever and then the blind of his ejection seat, and eventually found himself on the surface, in the wake of the carrier, safe and sound.

At the time the Royal Navy was losing 10 air crew a year in what seemed to be survivable crashes into the water; the United States Navy was losing 50. I was given the task of investigating the problems of escape from a sinking aircraft, and of finding out whether it might be possible to use the ejection seat as a means of underwater escape. After discussions with experts in the Navy on the matter, the conclusion we reached was that the use of the ejection seat for escape from submerged aircraft was not feasible. It was on the very next day that McFarlane successfully used his.

Investigations continued using the Admiralty Hydro Ballistics Research Establishment, where there was a million gallon tank, 120 ft long, 30 ft wide and 40 ft deep with one side constructed entirely of windows of armoured glass. We carried out a series of trials with a Scimitar fuselage in this tank, and subsequently with other aircraft types, to try to assess just how difficult it was to escape from a sinking aircraft.

To this end a series of underwater firings were made in a boxed-off end of the tank at Farnborough. It soon became apparent that McFarlane had been extremely lucky. The standard firing mechanism simply would not fire if the seat were submerged. We concluded that in McFarlane's case, the canopy had unlocked, but had failed to come off. This had kept the firing head of the ejection gun dry, but only the primary cartridge had fired. That had been just sufficient to push the canopy off, so that the seat was able to clear the aircraft.

The challenge was to make the seat fire reliably underwater. This meant investigating four variables: acceleration, blast, pressure change, and drag. We looked at drag first. We constructed a metal trapeze with two bars, one for the subject to hang on to, the other to brace his feet against. The trapeze lay on the bottom of a 30 ft testing lake at Portsmouth, and was connected to a Jaguar car driven by a racing driver. The subject, wearing oxygen breathing apparatus, clung to the trapeze for dear life as the Jaguar accelerated from a standing start along the tow path. With the Jaguar moving at 30 mph, it proved possible to cling on for about 20 seconds. The problem of having the face piece swept off was cured by putting a polythene bag over one's head.

The drag forces were thus proven acceptable. Next came the problems associated with blast. After finding a satisfactory way to waterproof the firing mechanism and conducting a succession of runs with dummies to obtain measurements of blast, acceleration, and velocity, we decided to try the procedure on a real person. For the dummy, progressive increases in the amount of cordite were used, from an initial 250 grains to the full charge for the Mark II gun being used—1500 grains. For the real person, 1500 grains were used on the first try.

The ride was certainly memorable. The explosions of the primary and secondary cartridges were felt rather than heard. One was aware of a great pressure on the body, and particularly the arms, due to the drag. I believe I lost consciousness momentarily, for the high speed films showed that my hands were torn from the handle of the blind of the ejection seat, although I had no recollection of the fact. On arrival at the surface, there were no after effects other than feeling a little dazed. The next subject's experience was similar to my own. We were then instructed by the Director of Naval Air Warfare not to proceed with further live tests.

By 1950, ejection seats were being used that had more powerful cartridges (2300 grains of cordite) and a peak velocity through the water of 34 ft per second. The peak g was 7.7. Investigations began concerning the feasibility of underwater ejection with these seats, and permission was obtained to proceed with further live tests.

The experience of being accelerated through the water at up to 7.7 g, exposed to a blast from 2,300 grains of cordite and subjected to Q-forces of the order of 7 pounds per square inch (equivalent to 600 mph through the air) virtually overwhelmed the senses. Yet, a pilot subjected to such circumstances still had to keep enough presence of mind to be able to release from his seat and parachute and inflate his life jacket.

For several years I had been working on a somewhat different approach, a method of ejecting the seat by releasing compressed air into the seat gun. The air supply was used to inflate a bag in the back of the seat in order to push the ejected subject out of his seat and inflate his life jacket. At the surface, an automatic dinghy inflated around the pilot. By 1962 this system had been perfected and a series of escapes were carried out from submerged aircraft.

Other problems had to be solved, including determining how fast an aircraft would sink if downed in the ocean. We concluded that the easiest way to determine a craft's sink-rate was to sink it. Accordingly, several kinds of planes, including a Scimitar, were dropped repeatedly into the sea and were tracked with special underwater cameras. These studies made it possible to predict the sink rates for aircraft of various configurations and weights. In final tests with the underwater escape system, a Scimitar was catapulted from the deck of HMS *Centaur*, and in due course, an undamaged dummy pilot, with inflated life-jacket, arrived at the surface.

New aircraft required modified designs involving a much more powerful seat injection gun. The much increased blast meant further testing to see what the effects would be. I undertook this test after trials that convinced me that it could be done safely. The blast was impressive and sheared 24 quarter inch bolts supporting the back of the test seat. After effects were minimal, but subsequent trials using sheep indicated that I had been fortunate. We concluded that underwater ejection with this gun was not feasible.

Q-force Investigation

Water is more than 800 times denser than air, so that a velocity through the water of 34 ft per second is equivalent in terms of drag and Q-force to velocity through air of almost 90 ft per second or 600 mph. The Q-force in both instances would be about 7 psi. My colleague, Captain E. L. Beckman, an Exchange Medical Officer at the Institute of Aviation Medicine, thought that driving a subject through the water at velocities of up to 22 mph would be equivalent to ejecting him into air-blast at 600 mph, but the effects on the body and the evaluation of restraint systems could be carried out in a much more controlled way under water. At 22 mph, the separation force tending to push the legs apart proved to be 300 pounds. The general sensation was described as "swamping the senses." It was determined that the limit of tolerance to ram pressure had been reached.

We have here the first instance of an underwater technique being applied directly to a solution of an aviation problem. There were to be others.

The Break Off Phenomenon

About this time reports were coming in of Canberra pilots flying at altitudes in excess of 40,000 ft who experienced a feeling of dissociation, described as "flying the aircraft but not being in it." There was total silence in the cockpit. All gauges were steady. The sky ahead and above was a uniform dark blue. Some pilots felt very apprehensive, and the condition became known as the "break-off phenomenon." At the same time there were reports of the Russians isolating people in blacked-out, sound-proofed rooms, as an aid to brain-washing.

Dr. Michael Bennett of the Institute of Aviation Medicine and I thought these examples of reduction of the sensory environment had something in common. We decided to produce the most complete reduction of the environment possible. An underwater breathing apparatus was designed such that a subject could be floated underwater at a temperature of 93 degrees Farenheit with a silent gas supply, so that the subject could hear nothing, see nothing, and feel nothing—a sort of back-to-the-womb experience.

Twenty one subjects found the experience delightfully relaxing and invariably fell asleep sooner or later. However, two became extremely disturbed within 10 minutes, fought their way up out of the water and remained hypomanic for the next 12 hours. Both were convinced that we had been playing tricks with them. One was certain that we were draining the water from the pool and the other that we were spinning him round and round. What had happened?

After careful analysis, we concluded that the key factor involved was stress. The 21 contented subjects were divers or individuals who had helped construct the equipment and were totally familiar with it. The two disturbed subjects were doctors who had taken part in many experiments but had never before been underwater, and they were apprehensive from the start.

Reduction of the environment per se is not frightening. You do everything you can to achieve it when you go to bed—turn off the radio, turn out the light, pull the pillow over your head to keep out the sound of the church clock striking, tell the other occupant of the bed to shut up and go to sleep. But if you are in bed alone, in a completely dark room, in an empty unfamiliar house, and you wake up and hear the slightest inexplicable noise, your pulse races, your blood pressure elevates, and you are afraid. Isolation per se is not frightening. Isolation plus stress is a different matter altogether. Although the physical conditions remain the same, familiarity with the environment soon dispelled the apprehension of high altitude flight and the illusions that went with the "break off phenomenon."

Diver Heating Systems

In 1962, Mr. D. Burton of the Royal Aircraft Establishment addressed the annual meeting of Flying Personnel Medical Officers on a liquid-conditioned garment for the provision of aircrew cooling. His presentation went over like the proverbial lead balloon. The Institute of Aviation Medicine had been working for years on air-ventilated suits and were not about to be convinced that a liquid-conditioned suit might be a better idea.

Captain Beckman by now was back in the United States working on an underwater habitat programme called Sealab II. He was trying to find a way of keeping the divers warm and I suggested that the rejected Burton suit might be the answer by circulating hot water in it. I had no idea how much heat might be required but on the basis that it was designed for 300 W of cooling I suggested that he might start by using 300 W of heating. The U.S. Navy apparently took this as gospel because in 1968 when I was working there on the Sealab III project, there was a quarter million dollar nuclear isotope heater, designed to deliver 300 W to a liquid-conditioned suit from a plutonium 238 micro-reactor. I was the only person who ever swam this system which was beautifully fabricated in stainless steel and delivered all its heat to the ambient water and circulated the resulting four degree Centigrade water most efficiently. As a result it acted in the manner of a personal refrigeration plant and in addition delivered a not inconsiderable dose of neutrons and gamma rays!

By 1965, the National Aeronautics and Space Administration had built their own version of the Burton suit, the Apollo suit, which was used as a cooling garment for the lunar landings. Today, my company, Diving Unlimited International, Inc., markets a similar design of garment for maintaining thermal balance in commercial divers operating from lock-out submersibles.

We have here a fine example of what I have referred to as Upstairs/Downstairs.

Movement Control

If you sit in a chair and touch a target with a pencil a few times, then shut your eyes and try to hit the same point, you will normally come within a radius of ½ inch. When I tried this underwater, my blind touches were six inches above this target.

What this illustrates is that the strain receptors in the tendons learn the force patterns required of the muscles to touch the intended spot, and in so doing, they automatically take account of the support required from the anti-gravity muscles.

When the test is repeated underwater, the arm becomes virtually weightless and the anti-gravity muscles have nothing to do. But the central computer in the brain, which has been accustomed over a life time to counteract gravity, is temporarily deceived, and the combined result of support from the water and customary contraction of the anti-gravity muscles is to place the hand higher than the subject intended. This understanding of the customary role of the anti-gravity muscles has an important bearing on the problems of working in space.

Early attempts to simulate lunar gravity involved partially suspending objects by an arrangement of wires somewhat similar to that employed in training circus riders. Subsequent experience on the moon showed that quite good simulation had been achieved.

Later, parabolic aircraft flights were used to provide temporary weightlessness and trainee astronauts, in full space gear, endeavored to perform simple maneuvers such as climbing steps or recovering from a supine position. These efforts were hilarious to watch but no practical progress was made. Today's space-shuttle crews solved the problem by carrying out their training underwater, with a full sized space shuttle mock-up submerged in a tank at the Kennedy Space Center.

Applications In Submersible Design

The one-man one-atmosphere diving suit, *Jim*, resembles the suits worn by astronauts in a number of respects. Although designed to withstand great pressure rather than the lack of it, *Jim* has articulated limbs, self-contained life-support, and is muscle-powered, as are space suits. For underwater exploration, several variations on the theme of one-man systems have been developed in the last decade, with a general trend away from anthropomorphic styles. Thrusters have replaced legs for mobility and metal and plastic manipulators have replaced arms operating in metal sleeves.

The most ingenious and practical thus far developed is a system called *Deep Rover,* a machine that combines the advantages of a diving suit (small, agile, portable) with those of a larger submersible (space to change clothes, carry supplies and instruments, life support for a week). Deep Rover can descend to 1 kilometer in its Mark I form; a deeper version will ultimately go to 10 kilometers. The pilot sits within a clear acrylic sphere in a comfortable aircraft-style seat and controls movements of the sub through subtle motions of his forearm. Muscle-powered metal sleeves have given way to two sensory manipulators that simulate touch, force, and motion, can be controlled to within .03 mm, and can lift more than 200 pounds each.

Discussions are underway concerning the possibility of adapting a design resembling *Deep Rover* for use in space, not replacing present systems, but complementing them with a different approach that already has proven to be valuable in numerous applications subsea.

Designer of *Deep Rover,* Graham Hawkes, has advised me that a manipulator closely resembling one of *Deep Rover*'s arms, soon will be delivered to NASA for Space Station applications. This is a clear example of something developed for applications "downstairs" now being adapted for use "upstairs."

Conclusion

In conclusion, we have looked at some common human factors in high altitude flight and in deep penetration into the ocean. A practical knowledge of diving can be useful for one engaged in aviation and space research, just as a knowledge of the latter is of advantage in research into diving and submarine operations.

"Freedom to Move"

Paul B. MacCready, Jr.

Chairman of the Board,
AeroVironment, Inc.

The film, "A Freedom to Move" was provided for the Symposium by the IMAX Corporation, and Circus World and its staff generously made available its facility for the showing. With beauty, breadth, humor, and insight, this theme film of Expo '86 in Vancouver, gave a dramatic sendoff to the Lindbergh Symposium. The film depicts a balance between technology and nature, with spectacular images on a 90′ × 60′ screen. Woven through the film was a human story of an Eskimo family using ingenious, available technology to meet their transportation needs. This perspective, added to sequences of muscle powered "transportation" (old and new bicycles, fast streamlined tricycles, a pedaled hydrofoil, and a pedaled airplane) was melded with breath-taking views of aircraft, trains, and the space shuttle.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 1–11, March 1986

The Active Museum: Stimulating Public Involvement in Aerospace

Walter J. Boyne

Director, National Air and Space Museum

It is a very great pleasure to be a participant in the Lindbergh Symposium and to meet with this distinguished group. I would like to present some views that may not have the fundamental scientific importance of some of the other subjects of the symposium, but may be cogent in the sense that public awareness is going to be increasingly important not only in the appreciation of the subjects that will be covered but also in their funding.

We are all conscious of the spectator sport syndrome which has afflicted or enhanced our country, depending upon the point of view. The public is bombarded with media presentations of all types—from super bowls to presidential elections—and has in the process I believe, become not only jaded, but like hardy mosquito survivors of the pesticide wars, acclimated to the process. Part of the acclimation is a disinclination to participate actively, and one senses that there may be some confusion as to the relationship of a blank screen to an open mind.

A museum is particularly susceptible to passive acceptance by the visitor. There are, after all, and mercifully, no tests given to measure how much is understood of the museum experience. Perhaps the most rigorous test is repeat attendance; if on a visit to Paris the wife does the right side of the Louvre and the husband the left, never to return, can one say that it was a good experience, or even that the Louvre—or any museum in a similar situation, has done its job? I think not. Museums do not provide capsules of knowledge that may be ingested and taken away. They offer instead an opportunity to browse, to sense, to inspire, to provoke further reading, to become excited, and the measure of success might well be the frequency by which visitors return to enhance their enjoyment and their learning. Now the word most frequently heard that describes the typical understanding of the way a museum accomplishes this is "interaction," implying that the visitor has a hands-on experience which intensifies his enjoyment and his learning. I submit to you that interaction is important—but in a different sense.

The National Air and Space Museum (NASM) has for the past several years attempted to achieve its goals of education by providing the kind of environment just described, an atmosphere traditional in the sense that there are artifacts and labels, yet different in that there are consistent and deliberate efforts to involve individuals not just in the excitement of aviation and space subjects, but into a *personal* relationship with them. Parenthetically I should state that there is not, as often assumed, a natural American interest in air and space that automatically drives people to museums on the subject. In fact, there is some good evidence that the reverse is true, that the hard-edged concepts of technology may in fact "turn people off." One basis for this comment is the relatively low attendance at air and space museums around the world.

In the process of establishing an environment of conventional interaction, NASM was faced with some problems that forced it to take another look at the concept of "interaction" and to expand upon it. The problems stemmed from the traffic and the limits on space even in a very large building. An "interactive" exhibit of the kind that is done so well at the Exploratorium in San Francisco or the Toronto Science Center, requires that the visitor spend some time, usually three or four minutes, perhaps even more; often a docent or a staff person is available for explanations. At NASM the traffic, with visitation ranging from 9,000,000 to perhaps 12,000,000 per year, makes such individually tailored treatment almost impossible. We have done it in the past with exhibits ranging from computers to aircraft simulators, and found that it results in long queues, prohibitively high maintenance costs and more often that not, disgruntled visitors who do not wish to wait in line.

Yet the concept of interaction is terribly important, and we have over the past several years evolved a philosophy which expands the concept to a scale that is both manageable by us and attractive and useful to the visitor. It became apparent that we would have to modify our past ideas on how a museum should function in relation to "the other world"—the world of research, academe, and even the world of business. We wish to root out the idea of a hat-in-hand approach to the world and to completely eliminate *the idea* of waiting passively for something to happen.

Another important consideration is to ensure that the expanded concept never loses its rooting to the public as the most important aspect of the museum. In this regard, we consider the public not only to be the museum visitor, but also the end user of the research that is done. To achieve this we must place special demands upon our curators. It is not unusual in the museum world for curators to have their *peers* as the targets for their research and exhibits; this is only human. However, at NASM, curators are given a double task. They must do solid research which results in publications that are well received by their peers, *and* they must do research and exhibits which attract, entertain, and educate the public. The important twist is that these must *also* be of a standard that wins approval from their peers, for academic and scientific worth, this is very difficult to do. We've found that a casual visitor will spend as little as twenty seconds at an exhibit unless his curiosity is piqued. To pique that curiosity and yet convey the scientific information of which a scholar will approve is demanding indeed. But most importantly, it is also extremely rewarding, providing a psychic pay that involvement in exhibits work rarely does for a scholar.

As an important sidelight on the matter of exhibits, the museum tries to ensure that every exhibit is seen in the political, social, and economic context of its time, as well as in its technical and historical context. We feel that this is important interaction also. It is here that the cooperation of the exhibit designer and the curator becomes critically important, for sometimes more can be done with the fragment of a picture or a wisp of a song than a dozen labels can do. A grandmother, totally uninterested in aircraft all her life, might find new meaning in a racer of the 1930s when it is displayed in an exhibit which evokes the Depression, FDR, Babe Ruth, or Frederick March and Janet Gaynor (Figure 1).

In dealing with the world of business, we also made changes in philosophy. One change was in response; in any intercourse with representatives of any firm, we try to be immediately responsive and efficient, so that in dealing with the museum the

Fig. 1. The Golden Age of Flight Gallery

business people feel on familiar grounds. Another change was in the formula; we recognized that while many businesses have a great interest in philanthropy, they all have an interest in good business. We try to make a relationship with our museum good business every time. This doesn't mean that we debase the museum or permit its exploitation; it does mean that we do everything we can to ensure that the company gets recognition for its assistance, and this ranges from providing openings for events to giving the red carpet treatment to a visiting customer. It is time-consuming, certainly, but a special showing to a valued customer can be regarded by a business as more useful than a full page advertisement in the New York Times, and the company doesn't forget this the next time we approach them for assistance.

But the very most important thing that we do is make the public involved in the aerospace business, and in doing so provide the companies who help us with a climate in which to prosper.

Perhaps these points will become more apparent if I run through some of our new programs and underscore the ideas behind them.

The large format film—known as either IMAX or OMNIMAX, depending upon the type of theater, has for years been a profitable but highly controversial means to attract the visitor to a museum or science center. The controversy stemmed from a perceived dichotomy between films which entertained and films which educated. In a rather looping expansion of the idea of interaction, we felt that there was no reason that a good film should not do both, even though it could probably not do so inexpensively. So in the process of interaction we contacted The National Aeronautics and Space Administration and conveyed our interest in flying an IMAX camera on some shuttle flights. We contacted the IMAX film industry and held a competition for story boards for a film to be derived from such flights and we contacted industry for the funding.

In our solicitation of industry we offered to put up a substantial amount of cash as a firm indication of our interest and confidence in the success of the program. The result was a three party consortium, consisting of NASA, NASM, and the Lockheed Corporation which decided that the winning story board had been done by the IMAX Corporation (Figure 2).

NASM traditionally retained exclusive showing rights for its films; in this instance the new philosophy required a more statesman-like approach, and "The Dream is Alive" was released for other theater use as fast as prints could be made. The result has been the breaking of attendance records in every theater in which it has been shown. The general consensus is that it does in fact both entertain and educate, while at the same time raising profit levels in the theater and attendance at the associated facility, whether museum or a theme park.

From the business point of view, we again departed from tradition, for we created a contract in which the return from the film was to be divided upon the basis of the original investment. Now as an elucidation, it should be noted that NASM retained final authority on all matters relating to the content of the film. And to illustrate further the business aspects, NASM initiated a totally new process of competing for the distribution of the film, and arranging for a centralized program for the development of ancillary products. Returns from the film are distributed on the percentage basis of the investment, while returns from the ancillary products are split on a fifty/fifty basis. The results have been extraordinary in that the whole process of funding films like this is far more attractive to the prospective donor, who can see an opportunity not only for a return of his gift for other purposes, but even the possibility of making a net profit. The success of the methods used for "The Dream is Alive" were directly responsible for the rapid financing of a second IMAX film "On The Wing," which is to premiere on June 19th, 1986 (Figure 3).

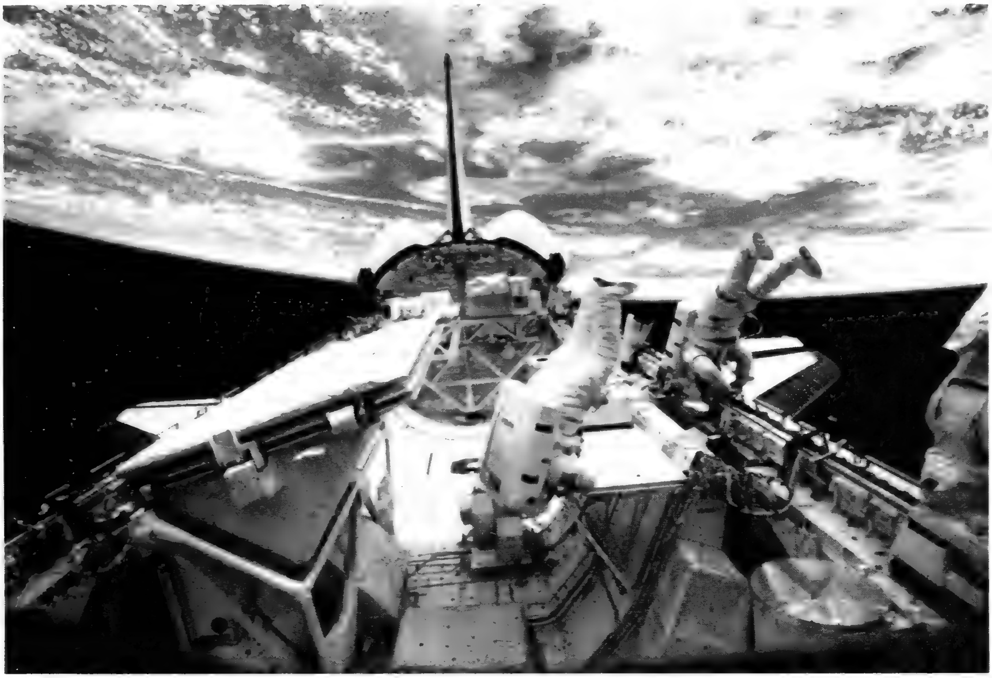

Fig. 2. Scene from "The Dream Is Alive," NASM's recently released IMAX film about the Space Shuttle. Shot aboard three separate missions on the Shuttle by the astronauts themselves, this film is described by them as "The next best thing to being there."

"On The Wing" offered an opportunity to once again entertain and educate, covering as it does the analogies between natural and mechanical flight. The Johnson Wax Company joined with us in this venture on terms similar to that created for "The Dream is Alive." There was yet another spin-off (Figure 4).

Part of the success of "The Dream Is Alive" could be attributed to the personalities of the astronauts. We sought a similar talisman for "On The Wing," and it came about quickly in a conversation I had with our chairperson, Dr. Paul MacCready, who had a long and well-developed interest in one of the most effective natural flyers of prehistory, the Quetzalcoatlus northropi. We reached an agreement and the S. J. Johnson Company kindly agreed to back the creation of *QN*, as it quickly became known.

From this discussion, we secured not only a film star but also immensely valuable aerodynamic and paleobiological scientific information.

Now the primary result of both films is an increase in the awareness of the museum visitor—all over the world—in aerospace subjects. We believe the interest stems because we have deliberately combined things of great natural interest: a relic of the dinosaur and flight.

Another program which does not lead to a film but does feature a combination of museum, academic and business cooperation is the Daedalus Project which we are conducting in concert with Dr. MacCready's friendly rivals at the Massachusetts Institute of Technology (Figure 5). We have a phased program which will result, we hope, in a human-powered vehicle which will fly from Crete to the Grecian Mainland sometime in 1987. You will note that we call it the Daedalus and not the Icarus Project. Once again we anticipate involving an industrial sponsor in a

Fig. 3. In June, 1986, "On The Wing" will premiere at the NASM. Produced by Francis Thompson, Inc. for the NASM and cosponsored by the Johnson Wax Company, this film is a lyrically moving analogy of mechanical and natural flight.

program which will have important scientific and educational results. And again, the fundamental purpose is to stimulate an awareness of the public in aerospace, this time by a dramatic aviation event using space age materials and engineering techniques to replicate a myth.

There are two other programs, both of which involve all the things we've been talking about.

Later this year, in September, an airplane designed by Burt Rutan and flown by his brother Dick and Jeana Yeager, will attempt a non-stop, non-refueled flight around the world in the world's largest all-composite aircraft (Figure 6). It is a voyage fraught with hazard and bursting with scientific return, for in its twelve to fourteen-day journey, much will be learned about aerodynamics, meteorology, human physiology and psychology. The airplane is described as miserable to fly or ride in, for it is designed for one thing—a record that has never before been attempted.

Voyager's journey will be controlled directly from the Milestones of Flight Gallery in the museum; upon the successful completion of the flight, the airplane will be installed in that gallery as an example of new materials, new aerodynamics and old fashioned vision and courage.

Our museum was faced, like all others with limitations of personnel, budget and physical space, yet we had a desire to become a genuine archival center for the world of aerospace. We had a collection of 2,000,000 photographs of air and space subjects, and the collection was subject to all the problems imaginable of conservation, indentification, access and especially distribution. We initiated a program of placing 100,000 photographs—and an index—on a single video disc which offered

Fig. 4. Quetzalcoatlus northropi, an 18 foot radio-controlled replica of the largest mammal to ever fly, successfully flew in January, 1986. He will star in "On The Wing."

instant access, no deterioration and easy transmission (Figure 7). While front end expenses were high, we found that reproduction costs were very low. We found that we would be able to provide discs at about $35 apiece and recover some costs; in other words, we'd be able to distribute 1,000,000 photographs on ten discs for $350. Response has been fantastic, particularly by industry.

The experience with the video disc made us determined to find a way to do the same thing for documents. There are many archives relating to air and space, most poorly indexed and difficult to access. We determined to create a system which would enable us to capture those archives, store them inexpensively, index them automatically and retrieve them easily (Figure 8). The result is our system for digital display, for which we have a patent pending, and which is under license to numerous firms and museums and major government agencies.

The system indicates the process, for we would not have been able to create it without close cooperation with the leading firms in the industry; the result will be significant improvement in archives around the world.

Perhaps the most obvious example of our philosophy will be the new *Air & Space* Magazine, to be launched in April of this year (Figure 9). *Air & Space* will not be a magazine about the museum, but will attempt to capture the imagination of the magazine-reading public in the same way that the museum attempts to capture its visitors. The necessary relationship here between delivery of a product and industrial support is evident; the byproduct of this collaboration, increased public awareness of air and space will be the bonus for us all.

There are many more evidences of our philosophy in our research programs, especially from our Center for Earth and Planetary Studies Department, where the

Fig. 5. The Daedalus project will attempt a human-powered flight from Crete to the Grecian mainland.

Fig. 6. Voyager, designed by Burt Rutan, will attempt the first around the world, non-stop, non-refuelled flight, the only major milestone not yet accomplished.

Fig. 7. NASM videodisc system: each disc contains 100,000 photographs.

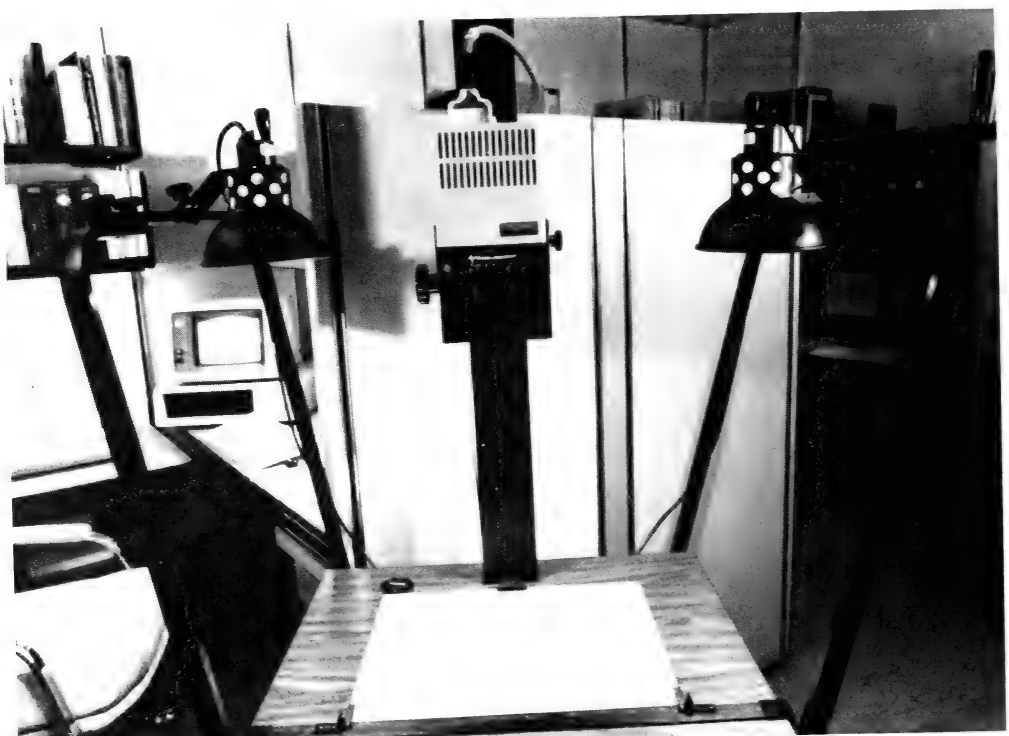

Fig. 8. NASM's System for Digital Display: archival storage, indexing, and retrieval system for collections management.

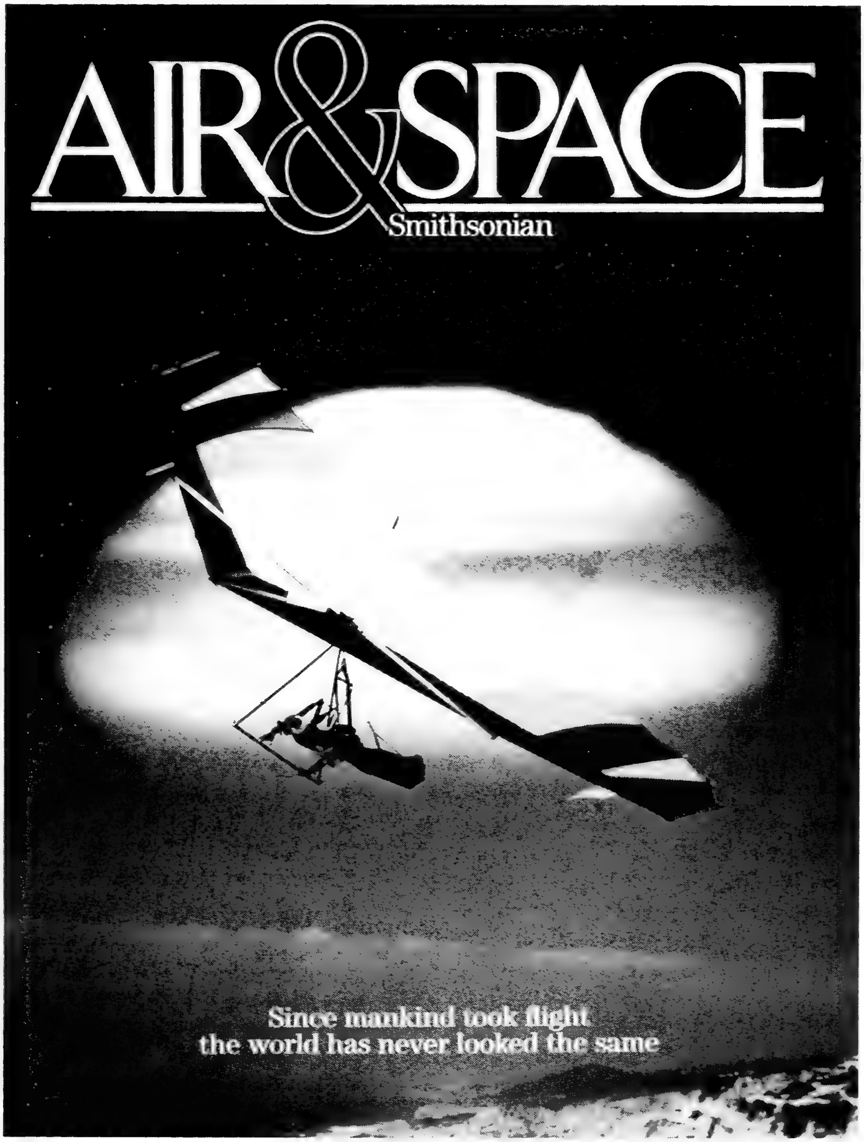

Fig. 9. *Air & Space*: The NASM's new magazine, designed to capture the imagination of inquisitive minds, will launch its first issue in April 1986.

analysis of remote sensing devices is corroborated by field treks to Southern Egypt and Central Mali. Each of our other departments has similar active programs which relate directly to science, industry and the public.

In closing, I would just reemphasize that the role of a museum must change over time as the role of any organization must; for a museum devoted to the technological developments of air and space, it is a natural consequence to use those developments to cement the relationship we seek with the public, academe and business.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 12–15, March 1986

Biological Flight, Mechanical Flight, and Efficient Transportation

Paul B. MacCready

Chairman of the Board, AeroVironment, Inc.

Introduction

The broad ecological niche of flight has been well occupied by nature for over two hundred million years. There have been insects, birds, bats, and pterosaurs (and we can even include flying fish, drifting spider webs and seedpods, and gliding animals). In the last hundred years man has authoritatively entered the niche via airplanes, after edging into it earlier with balloons and kites.

The flight entities which most obviously provide links between nature and aircraft are the larger natural fliers and the smaller, lighter, and slower man-carrying devices. The seagull, the hawk, and the giant pterodactyl are not far from the sailplane, or the hang glider, or the human powered airplane. Natural flight also includes the gnat and grasshopper and wren, and artificial flight includes the airliner and shuttle, but the connection between such disparate creations is more tenuous than for those which are more alike in size and function.

Unusual circumstances in the past decade have gotten me into the human powered airplane field. Here man must get by on muscle power, and so is forced into exploring efficiency and the limitations of flight more through a birds eyes or brain than is the case with ordinary aircraft.

For the past year, my associates and I have been developing a flying replica of the largest flying animal: a radio controlled, battery powered, wing-flapping-propulsion reconstruction of the pterodactyl Quetzalcoatlus northropi (QN™). This tailless creature was bigger in wing span than some four-person aircraft. To handle its structure and stability and control has required modern aeronautical technology.

Both the human powered aircraft and the QN replica projects will be described, representing constructions on the border between natural and artificial flight. The projects thus introduce consideration of the balance between technology and nature.

Human Powered and Solar Powered Flight

A fit human can develop about one-quarter horsepower for a few minutes. This is a sorry performance for a 150-pound "engine," inasmuch as the burning of fossil fuel in a modern reciprocating aircraft engine of similar weight produces some 400 times as much power. Big power, and stronger structures than obtainable with bone and sinew, have permitted man's aircraft to outstrip dramatically the performance of nature's fliers. The designers of aircraft now have little interest in biologically powered flight.

In 1959 Henry Kremer put up a large prize for the first sustained/controlled human-powered flight. Seventeen years later, my need to pay off a large financial obligation incurred by a relative drew my attention to this Kremer Prize. The correlation between the prize amount, about $100,000, and the debt amount, about $100,000, proved irresistable. By a lateral thinking process I arrived at a suitable approach to meeting the challenge. Then in a year-long intensive 'hobby' project, our team of friends and family won the prize with the Gossamer Condor (96-foot span, 70 lbs.). Perhaps the most valuable reward, for the outside world as well as for us who constituted the development team, is the broadening perspectives which arise as one pushes into new areas. In the U.S. the approach to making a better vehicle has usually involved putting in a more powerful engine. However, in this case Henry Kremer provided a very different challenge. He asked, in effect, for an airplane to fly on one-quarter horsepower. It turned out this challenge could be met by pushing hard on the frontiers of structures and aerodynamics. The project became a dramatic example of doing more with less—less material, and less power—a useful perspective as expanding civilization struggles into the era of limits on our non-expanding globe.

After the Gossamer Condor program, a new and larger Kremer Prize stimulated our development of the Gossamer Albatross. This more elegant human powered vehicle achieved a flight across the English Channel lasting almost three hours. On a subsequent program our human powered Bionic Bat won two Kremer speed prizes. This aircraft serves as a technology demonstrator for some other interests of ours: a long duration drone to carry a radio repeater aloft for weeks at a time, and a safe, very slow flying sailplane in which you can join hawks spiralling in a tiny thermal, at their same speed and turning radius. In 1981 our Solar Challenger carried a pilot 163 miles from Paris to England powered solely by sunbeams shining on its 16,000 photovoltaic cells. The aim was to stimulate public appreciation for the potential of solar cells as a future energy resource (for use in ground installations, not vehicles).

The Giant Pterodactyl

The latest project brings back to "life" the largest flying creature which ever existed, a giant pterodactyl with the giant name Quetzalcoatlus northropi and the formidable size of a four-person airplane (a 36-foot wingspan). In common with all land and airborne animals bigger than about 45 pounds, it did not survive the "great extinction" 63 million years ago. Our replica is radio controlled, battery powered, propelled by wing-flapping, and looks and flies like the original. It is to help publicize, and be an actor in, a forthcoming, wide screen IMAX film, titled "On the Wing."

Johnson Wax and the Air and Space Museum are sponsoring both the film and the QN replica. The film illustrates the evolution of natural flight with insects, birds, bats, and the pterodactyl, and relates their evolution to the development of aircraft. QN will appear at the beginning, as a natural flier, and then at the end when the point is made that modern aerospace technology is required for duplicating nature even crudely.

In 1984, a QN feasibility study was conducted which included the bringing together of paleontologists, aerodynamicists, and structures and autopilot specialists to develop a position about the likely size, appearance, and lifestyle of the original animal, and to assess the probability that a mechanical replica could fly satisfactorily. The subsequent development project took place in 1985. In January, 1986, the spectacular filming of flights of an 18′ span replica took place at Race Track Dry Lake near Death Valley. This was the size of an adolescent Quetzalcoatlus northropi, (and the same size as a dozen sets of fossil bones which may have belonged to the same species). Being identical in appearance and flight characteristics to the 36′ one, this replica served perfectly as the lead actor in the film; a temperamental actor, but handsome and talented. The IMAX film "On the Wing" will be premiering at the National Air and Space Museum in Washington in mid June of 1986. Public flights and display of the 18′ actor are under discussion, as well as the eventual construction and demonstration of the ultimate 36′ version.

The radio controlled flying QN replica has three sensors, 13 electric motor "muscles," and a complex computer brain—but is still a thousand-fold less complex than the real thing. The main challenge is that the creature had no tail but instead a huge head extending forward on a long neck. It was unstable and so had to employ active control to stay upright. This is hard to duplicate with man-made mechanisms.

The history of the QN replica program is given in articles by MacCready in Research Report 1985 of the National Air and Space Museum, and in the November 1985 issue of Engineering and Science, published by the California Institute of Technology. The program is also reaching the popular media in the spring of 1986 in articles in Science '86, Popular Science, Life, Smithsonian Magazine, etc. Thus details need not be provided here.

As QN flies overhead, an observer will be able to "experience" the majesty of nature's creation. The flight will combine the intimacy of a zoo with the historical grasp of a museum. Each observer will better appreciate nature's dramatic flair, and, in learning about the great extinction, may perhaps consider if we are now putting ecological pressures on our fragile planet similar to those of 63 million years ago.

Efficiency

There are many ways of defining aerial transportation efficiency. There are criteria of fuel use, speed, economics, reliability, and versatility and convenience, and questions such as whether the weight carried refers to gross weight or a payload. Nevertheless, for our purposes here, relating biological flight to mechanical flight, we can ignore definition details and still make several significant generalizations.

First, the basic efficiency of the propulsion systems of birds and propeller aircraft are rather similar. Both wing propulsion and propeller propulsion efficiencies are generally in the same range, say plus or minus 10% from a reference 80%. The efficiency of generating power burning chemical fuel is also comparable, whether it is the lipids burned by a bird during migration or gasoline burned by an aircraft engine. A bird burning up half of its initial body weight during a migration may go 2,000 miles non-stop; an airplane consuming half its takeoff weight in fuel may go about four times as far. The better relative range performance of the airplane arises because it has a flatter glide than the bird, (a better lift to drag ratio), a performance advantage available to the airplane primarily because of two factors. One factor is a scale effect: the airplane operates at a much higher "Reynold's Number" than the bird, and therefore for the airplane viscous effects are relatively less critical. The other factor is that the structural techniques and the non-versatile function of the airplane permit a wing better tailored to aerodynamic efficiency in cruising flight (say a higher aspect ratio).

Conclusion

Biological flight, specifically bird flight, has been the catalyst for the initial development of man's aircraft. As these aircraft achieved fantastic flight performances, the role model function of birds tended to be forgotten. The giant pterodactyl, a much larger animal than aeronautical engineers of a decade ago assumed could fly, alerts us to the suspicion that nature may still have some surprising and valuable insights for us. As we explore bird characteristics we are reimpressed with what a magnificent engineer nature is. A bird's flight versatility and performance can in some respects be far beyond that of any airplane. Consider the Guillimot, which operates very well in the air, on land and water, and under the water. Consider the Sooty tern, reputed to stay aloft on one flight for years (using aerial refueling by snatching up squid without landing). Consider the Artic tern on its long migration a third of the way around the world, without instruction, reaching a location which its parents knew. And consider the ability of birds to take off and land on a confined spot.

The aeronautical creations of man and nature are closely related. Each is wonderful in its own way. We are more familiar with the features of airplanes than the features of birds, an inbalance that deserves correction.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 15–20, March 1986

Aviation Transportation—A Possible Future

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ABSTRACT

Air travel across the Pacific has increased markedly in recent years, even though a trip between the U.S. and Japan or China requires twenty plus hours. Space Shuttle missions now occurring regularly orbit the entire globe in 90 minutes, so it is obvious that existing technology could provide faster transoceanic service. More efficient and flexible launch capabilities for space missions and the need for faster intercontinental travel can both be served by combining aerodynamic lift for takeoff and landing from large airports, with hybrid airbreathing and rocket propulsion systems.

As petroleum products are projected to be exhausted in about 30 years, it is desirable that future aerospace vehicles be designed for alternate fuels. Hydrogen is well established as a fuel for space missions and also offers many advantages for jet propulsion: it is 2.77 times as energetic as jet propulsion fuel, it can readily be made from water using solar energy, and its prinicipal exhaust product is water that is non-polluting and recyclable. Other advantages such as its heat sink capacity are also cited.

Two options for transoceanic transports are likely to evolve, a suborbital transatmospheric vehicle and a hypersonic cruise aircraft. Both would marry airbreathing-rocket propulsion and aerodynamic lift technologies with space shuttle landing capabilities.

In summary, the next major advances in aeronautical transport could be more of an offshoot of space developments than an evolutionary step beyond the air transports of today. Hydrogen will enhance the balance between technology and the environment, because of its non-polluting qualities and its inexhaustible supply. Time is the most precious and irreplaceable resource of man and it is concluded that shortening travel hours using a fuel produced from water and sunlight is in harmony with nature.

In his book of the 1880's entitled "Bird Flight as the Basis of Aviation," Otto Lilienthal distinctly stated the challenge of his day:

"It must not remain our desire only to acquire the art of the bird, nay, it is our duty not to rest until we have attained to a perfect scientific conception of the problem of flight, even though as the result of such endeavors we arrive at the conclusion that we shall never be able to transfer our highway to the air. But it may also be that our investigations will teach us to artificially imitate what nature demonstrates to us daily in bird flight."

Lilienthal not only issued this charge, he pursued it with fierce determination until his untimely death during a test flight of his own flying machine design in 1896.

Considering the thousands of years man had envied the abilities of birds, it is unlikely that Lilienthal expected him to achieve more than the equivalence or a semblance of bird flight. His own successes provided convincing evidence that men would fly someday, but it is doubtful that even his wildest dreams envisioned the flight of passenger-carrying airliners. His conservatism was evident when he encouraged study of the birds "—even though—we arrive at the conclusion that we shall never be able to transfer our highway to the air."

Only a little more than twenty five years later, Charles Lindbergh had resoundingly answered the challenge of Lilienthal. Not only did he fly like the birds, but he went faster and farther. Mankind everywhere was amazed and inspired, but even then most practical-minded persons asked, "What good is it?" One man flying alone across the Atlantic was certainly a significant accomplishment, but a dreamer might not have guessed that before two decades had passed, 120 passenger airliners would put 3,000 passenger oceanliners out of business.

It has been like that since the Wright brothers' first successful powered flight in 1903. One must be awed by the almost unbelievable progress in flight, yet we still have difficulty envisioning the future. Perhaps by reviewing some of the key milestones of aviation history, we can prepare to expect possibilities that could happen relatively soon.

In December, 1985, we celebrated the fiftieth anniversary of the first flight of the Douglas DC-3. Barely ten years after Lindbergh's Atlantic crossing, this huge shiny airliner began making air travel a reality for millions of people, at the astounding rate of 21 passengers plus a crew of three. Compared to existing forms of surface transportation, it revolutionized cross-country travel, and within a decade it was followed by bigger and faster models employing four engines and evolutionary technologies. It was the 120 passenger versions of the DC-6's and Constellations that took the transoceanic passenger trade away from the luxury liners in a few short years.

World War II spawned many technology advances, but the next hallmark for aviation transportation was to be the flight of the Comet jet transport in 1952. Although this first model amazed the world with its dazzling speed and high altitude capabilities, many experts doubted the jet aircraft would succeed as a prime mover of people and freight, because of jet engine demands for huge quantities of fuel. But rapid gains in fuel efficiency and the high productivity of jet transports soon made them a way of life.

Perhaps this is the time to mention the relevance of productivity, for this essence is the often overlooked benefit from higher speed transportation systems. When comparing travel costs of vehicles that travel at about the same speed, it is appropriate to consider the costs/seat mile as a figure of merit. When the speeds are greatly different, as for example, between the ship and the jet airplane, time becomes an important parameter in the economic equation. To illustrate, a single 747 jet transport carried more passengers across the Atlantic last year on a normal schedule than the Queen Mary carried during a prime year in its heyday, and at one tenth the cost. In all, some 22 million people flew the Atlantic last year.

The past two decades of jet transport evolution have produced bigger and better aircraft, but attempts toward efficient supersonic transports have not fully succeeded. To give credit where it is due, the Concorde has established a place for limited transoceanic routes, and it has just completed ten years of service by carrying more than a million passengers about 100 million miles. The Russians gave up on their SST entry after several bad crashes and deficit operations from the beginning. Our own U.S. efforts to develop a supersonic transport were thwarted in 1971 by problems of incompatibliity with our environment, and a "Who needs it" reaction from many quarters. Other concurrent advances such as the wide-bodies have served us well, however, and many would say that present air travel growth suggests that needs are being satisfied.

So why would we want anything more? Well, for one reason, trans-Pacific and other international trade activities have increased markedly in recent years. This means that a lot more people are traveling twenty plus hours by air to do business with counterparts on the other side of the world. Not only are more people desirous of faster transportation, there is a growing awareness that technologies exist which could make faster travel possible. As Space Shuttle flights occur every few weeks, it is frequent that astronauts make fifteen orbits around the entire world while a commercial air traveler spends the same amount of time traveling from the U.S. to Japan. Looking back we see that when an "aviation first" signaled technology readiness, opportunity was often coupled with an obvious desire or perceived need, so that new capabilities were not long in coming. Accepting this "de facto" premise, let us speculate on future possibilities.

A historic milestone for space travel occurred in 1961, when Yuri Gagarin successfully orbited the earth in one hour and 48 minutes. His flight in some ways produced the same reaction from people that Lindbergh's had: awe for the dramatic achievement, but the same question, "What good is it?" A one-place capsule launched atop a "controlled explosion" called a rocket, and a relatively uncontrolled landing by parachute could hardly be considered a harbinger of future transportation systems. Even after missions to earth orbit became routine, and Apollo had carried a dozen Americans to the surface of the moon, there were still many challenges to face before realizing commercial viability of space vehicles.

The Space Shuttle, a composite of aeronautical and missile technologies, has clearly brought us closer with its remarkable ability to carry passengers and cargo into space and land at large airports using aerodynamic lift like an airplane. Many of you will recall the skeptics who were appalled at the thought of returning from space to a landing without propulsion, even though the technologies for gliding flight have been used successfully since Lilienthal's experiments. But rocket launches that must now occur at Cape Kennedy, and the requirement for ferry flights from the landing to the launch site, severely limit the application of shuttle technology for transportation between points on earth. Furthermore, space commercialization and military missions would benefit greatly if launches could occur from existing airport facilities instead of specialized launch complexes.

This assessment suggests that aeronautics and space technologies will soon be blended further. The reason is simply that technologies appear ready for new applications, and now there are TWO basic needs to be served: intercontinental travelers sorely need a means of going six thousand nautical miles in less than three hours, and space missions need launch and landing capabilities from airport facilities around the globe. Both needs can be served by combining aerodynamic lift for takeoff, climb and landing, with airbreathing and rocket propulsion technologies.

As airplanes have always exploited the atmosphere for both propulsion and lift, future generations will not question this method for improving the operational efficiency of space travel. Various hybrid propulsion systems have been envisioned for years, and while efficient, practical systems are yet to be built, there is ample evidence that turbo-ramjet-rocket combinations may be achieved after reasonable development efforts.

What I also suggest is that hydrogen will become the aviation fuel of the future. This is not so obvious to our generation, accustomed to transportation systems that are dependent on petrochemicals pumped from the ground. But the application of hydrogen to space missions has done much to ensure technological readiness as well as economic competitiveness, and there are other compelling reasons for this fuel. More will be said about tradeoffs in a moment, but first, let me share basic calculations using a kind of logic I imagine Lindbergh might have appreciated.

Last year the world use of petroleum products amounted to about 20 billion barrels of oil. If this flow from the ground were likened to a river of oil, it could be represented as a stream 100 feet wide, ten feet deep, flowing with a current of about three miles per hour. Projections of the amount of oil left in our Earth's "tank" are somewhat uncertain, however, several respected estimates indicate the world-wide reserve to be about 650 billion barrels. At the current rate of use, that supply will last the world users about 30 years. What worries me as an American is that we are the largest user at about 29%, and yet we have a US reserve of only 4% or 28 billion barrels. If forced to depend on our own reserves, we would exhaust our supply within five years. Whether the exhaustion date is really five or thirty years from now, it is apparent that designing our next generation air transportation systems to use another fuel not only has merit, it is essential.

The high specific energy of hydrogen has led to many studies of its application as a fuel over the years. One pound of hydrogen offers 2.77 times as much energy as a pound of JP fuel. Hydrogen is the most abundant element in the universe, and its supply is virtually inexhaustible. It can be readily made from water, although energy is required for electrolysis.

Successful flight experiments employing hydrogen in conventional turbojet engines were conducted in 1957 by the NACA Lewis laboratory, and it was shown to be compatible with jet engine applications. Its high heat of combustion offers major increases in engine performance, and environmentally, it is unusually clean burning, as its primary exhaust product is water. It has been used effectively in rockets for years, providing valuable experience and establishing confidence in our ability to apply hydrogen as a fuel.

For very high speed flight where aerodynamic heating is a problem, hydrogen offers yet another benefit, because as a cold liquid at temperatures of about minus 400 degrees Fahrenheit, it has a heat sink capacity about 38 times that of JP fuel at 100 degrees F. This property can be used for cooling structures and surfaces, for both strength and aerodynamic benefits, although complexities in design and weight penalties result. Another advantage of hydrogen as a fuel accrues from its ability to combust rapidly. It can react with air at supersonic speeds in combustion chambers of a practical size, with relatively high aerodynamic and chemical efficiencies.

Hydrogen has been produced for years using electrical energy to split water (H_2O) molecules. At present, commercial production of hydrogen involves costs for electricity that are greater than the equivalent of petrochemical fuels, however very promising research is underway toward the use of solar energy obtained from solar cells immersed in the water being split. Efficiencies being achieved in the laboratory show promise of production costs far less than those involving electrical energy generated by other means.

For completeness, two negative aspects of hydrogen to flying applications are its relatively low density and the fact that it must be stored in special insulated containers to maintain it as a liquid. The low density dictates larger tank sizes that tend to increase aerodynamic drag, and the cryogenic storage requirements make structures and tankage more costly and heavier. When all the tradeoffs are considered, however, studies show big advantages for hydrogen as a fuel for future air transportation systems. It goes without saying that an infrastructure must be developed for a hydrogen economy if hydrogen is to be widely used as an aviation fuel. The cost of a change in fuel from a petrochemical base will be borne by a large number of users, but leadership for the changeover will be provided by aerospace.

Two options exist for vehicles especially suited to the trans-Pacific ranges: transatmospheric or suborbital aerospace planes, and hypersonic cruise aircraft. The first would marry airbreathing-rocket hybrid space vehicle and aerodynamic lift technologies with Space Shuttle landing capabilities. The second would be shuttle-like aircraft accelerated to hypersonic cruise conditions using a turbo-ramjet-rocket propulsion system that would cruise at altitudes of 100,000 feet or more. Space launch requirements may encourage the earlier development of the suborbital or transatmospheric technologies, but efficiencies will probably favor the hypersonic cruise vehicles for intercontinental transports. Military applications may actually dictate the timing of advances, but it seems a safe bet that both concepts will be tested within the next ten to twenty years.

In summary, I believe we will see the next major advance in aeronautical transportation as more of an offshoot of space developments than as an evolutionary step beyond the jet transports of today.

In his later years, Lindbergh's writings admonished us that our advances in science and technology were not being paced by advances in our social or ethical mores. His feelings seemd torn between the same innate drives to improve our technological position that he exhibited when he was charting a course for aviation, and uncertainties as to whether men were capable of continuing without destruction of other values—even life itself. In an article called "The Wisdom of Wildness", his conclusion was contained in a final, simple sentence: "The Human Future depends on our ability to combine the knowledge of science with the wisdom of wildness."

Along with most of you, I share his concerns. And yet I believe it is right to continue flying higher and faster. Man's creativity and ability to reason right from wrong are the attributes which distinguish us from other creatures, and I believe God intended us to use these gifts to improve the quality of life. A blend of space flight and atmospheric flight sciences will give us more time for creativity, and shortening travel involving hours of inactivity will afford better uses of our talents. What matters is how we apply our technological advances and how they influence the whole of our environment and relationships. Real progress is only to be judged after the harmony of our developments with nature is clear.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 21–24, March 1986

The Emergence of Treatment Technology in the Management of Hazardous Waste

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ABSTRACT

Until recently, the management of hazardous waste was largely dominated by various land disposal techniques, with its attendent uncertainties and predictable failures. With the enactment of the 1984 Resource Conservation and Recovery Act Amendments (RCRA), a watershed series of new policies and provisions governing the management of hazardous waste are being instituted which presumtively prohibit the land disposal of all hazardous wastes; structure the Agency's discretion to either affirm or override these presumptions by specified dates; support the prohibitions with a self-implementing program in the event the Agency fails to implement the prohibitions or establish pretreatment standards; and to close many of the loopholes in hazardous waste regulations that allowed "legal dumping" of hazardous wastes. These changes were brought about by a fundamental recognition of the delay and indecision caused by the lack of structure and direction in existing hazardous waste policy, and by the fact that no Agency, no matter how well intentioned, could accomplish all the necessary changes without direct, unequivocal directives from the statute itself. The article examines the conditions and terms that must exist for permanent protective treatment technologies to exist in a world and a marketplace where land disposal has previously been the order of the day.

There are two Federal statutes that govern different aspects of the nation's hazardous waste management activities. The "Superfund" law, which was first passed in 1980 to cleanup waste releases from past mismanagement, and the Resource Conservation and Recovery Act (RCRA), which was first passed in 1976 and is intended to prevent the creation of future problem sites through a series of controls

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on daily management. The 1984 Amendments to RCRA, also referred to as the Hazardous and Solid Waste Amendments (HSWA), is the most significant rewrite of any environmental law; restructuring our national policy and the regulatory decision-making process. While these changes have their roots in a period of unparalleled EPA turmoil, the major impetus was derived from a universal and mutual recognition of data, studies and conditions that argued for a complete change not only in the way in which wastes are managed, but also in the manner in which they are regulating them. In fact, fundamental change to the decision-making process is perhaps the greatest single contribution of the 1984 Amendments.

We are now in the midst of an unparalleled transition in the management of hazardous wastes, 10 years after the original enactment of RCRA. Relative to the Clean Air Act and Clean Water Act programs, controls on hazardous waste management are 10–15 years behind the progress of these early 1970 laws. Going back to early 1982 when the reauthorization process began, it was a confluence of political and technical voices and findings that helped forge the consensus as represented by the 1984 Amendments:

* new abandoned or problem sites (Superfund sites) were being discovered at a faster rate than we could clean them up; this dismal picture was compounded by the discovery that the regulations under the RCRA program, which governs the daily management of hazardous waste, was in fact the leading cause of our future Superfund sites. That is, the "legal dumping" of present day wastes was an equal if not greater danger than the illegal dumping of the past; more waste generators and facilities were exempt from regulation than were subject;
* ninety percent of all generators were exempt from regulation on the basis that they were "small generators";
* many wastes were not listed as hazardous, including dioxins and ethylene dibromide;
* all "recycling" practices were exempt from regulation. However, recycling was so broadly defined as to constitute any reuse of a hazardous waste that served a beneficial purpose to the user. As such, activities like the use of dioxin-containing wastes to oil roads in Times Beach were exempt "recycling" practices;
* there were no meaningful controls on air emissions from evaporation ponds, or on the placement of hazardous wastes into sewers (supposedly the province of the Clean Water Act);
* we discovered that there were 250 million tons of hazardous waste being generated, not 40 million, with approximately 80 percent of this volume being land disposed;
* there were no restrictions on what was being placed in the land, and no minimum technology requirements imposed at land disposal facilities such as dual liners and leachate collection systems;
* in fact, the tide of continued land disposal was so strong in early 1982 that even the most outlandish and exotic proposals by today's standards were being entertained. For example, a major paint and pigment firm was proposing to dispose of drummed volatile organic hazardous wastes in an abandoned salt mine under residential areas in Barberton, Ohio;

In short, the hole was bigger than the doughnut. At the same time we were also learning about the business of hazardous waste management, and the necessary regulatory and marketplace conditions for treatment technologies to exists:

* it was clear by early 1982 that unrestrained by regulation, hazardous wastes were like water running downhill, being disposed of along the path of least cost and least control. We recognized that technology cannot be

forced to compete against unrestricted land disposal, where cost alone dictated management choice;

* the Congressional Office of Technology Assessment and the National Academy of Sciences concluded that there was no shortage of techniques, ingenuity or methods to properly treat or render wastes non-hazardous. Rather, the real problem was with the regulations and loopholes themselves. The regulatory disparity between land disposal and treatment introduced significant uncertainty into the market for technologies. This lack of controls to ensure that all methods of management "played by the same rules" and provide equal certainty in protecting public health indirectly subsidized land disposal, and forced many firms to withhold additional investment in treatment technology;
* from the treatment industry's perspective, the real problem was not with the availability of methods to permanently treat hazardous wastes, but rather with the regulations themselves. The existing regulations governing hazardous wastes would have one believe that the universal maxims of "no free lunch" and "getting what you pay for" applied to everything but the management of hazardous wastes;
* we discovered that you cannot separate the desire for increased protection from the increased costs of waste specific, constituent specific treatment. There is no one step treatment process for every waste;

In short, the period from 1976 when RCRA was first passed to 1984 demonstrated that we had learned from or about the nature and causes of our hazardous waste problems then we instituted solutions to them. The 1984 Amendments closed these loopholes and marked the end of the beginning of the RCRA program by establishing the beginning of the end for unrestricted land disposal.

The heart of the 1984 Amendments lies not in any one provision, but rather in its approach to the regulatory process itself. We discovered that no administration, no matter how well intentioned, could accomplish all the necessary tasks without direct assistance from the statute itself. In addition, rather than simply directly EPA to go issue necessary regulations, the statute establishes a statutory presumption that prohibits land disposal of all wastes while allowing the Agency to selectively override these presumptions by establishing "pretreatment" conditions. The bill supports this presumption with a self-implementing statutory provision (frequently termed "hammers" or "minimum regulatory controls") that impose the prohibition without exception if the Agency fails to act in a timely manner.

It was clear by the end of the reauthorization process that discretion had become its own worst enemy; too much was as bad as too little. These new provisions and the fundamental restructuring of Agency discretion and the decision-making process is not intended to be punitive. Rather, they have two primary aims: to allow the Agency and the regulated community to focus its efforts on specific exceptions to a general prohibition rule, rather than to burden the Agency with justifying each restriction for each waste under a generally permissive scheme; and, it was intended to create incentives for the regulated community to become *constructively* involved in regulatory development, or live with a prohibition that has no exceptions.

If the heart of RCRA is its restructuring of Agency discretion and the decision-making process, the soul of RCRA is the search for certainty: certainty that wastes will be properly managed in the first instance; certainty that future generations will not have to bear the cost of current-day land disposal expediency; and certainty that the transition to permanent and protective methods of treatment will indeed occur on a timely and predictable basis. While these Amendments were instituted less than eighteen months ago, there is clear and convincing evidence that the scheme is working. The Agency is for the first time meeting many of its deadlines. A program office that previously could not meet a single regulatory deadline is now making more than it misses. The Amendments have provided the necessary certainty for firms to invest in and expand treatment capacity. New technologies and new applications of existing technologies have emerged to a significant degree, particularly the use of portable treatment technologies that can be brought to the site of a cleanup action or waste management site. Generators are making significant strides in reducing the volume of the wastes generated, particularly for aqueous organic wastes, many of which are now being recovered.

However, as T. S. Eliot was fond of saying, "Humankind cannot bear too much reality." In a field where there is a lot of reality to live up to, there surely will be many difficult days ahead: the early phase in implementing the land disposal ban has been far from smooth; pretreatment standards must be established that do not simply bless the status quo; critical decisions must be made on the future role of deep well injection; and creative use of waste codes and manifest data cannot be used in a way to evade the ban.

In fact, before the final transition is over, many firms will be put out of business, thousands of impoundments will be closed, major process changes will be instituted, and overall managers will be forced to take their waste management activities more seriously. In many ways, the 1984 Amendments bring to light a third fact of life: death, taxes, and no matter what we do wastes will be generated. It is my firm belief that the mutual recognition of the hard realities ahead, punctuated by a high level of participation stimulated by the 1984 Amendments should yield a program that is second to none, one which we can eventually look on with pride rather than look back on with chagrin.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 25–31, March 1986

The Hazardous Waste Superfund Program: Goals Versus Practices

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ABSTRACT

Superfund's major objective, as expressed by the Senate Environment Committee, is "to provide an incentive to those who manage hazardous substances or are responsible for contamination sites to avoid releases and to make maximum effort to clean up or mitigate the effects of any such release." Although the dominant thrust of the original Superfund law was to promote and advance the clean-up of sites, the pending 1986 amendments are aimed primarily at either eliminating perceived inefficiencies in or at expanding the scope of the present program. Among the controversial amendments discussed are provisions setting a mandatory schedule for various site inspection, study, and clean-up priorities; creating new Citizen Suit authority; limiting permissible uses of the Fund; extending of "fund balancing" requirements to privately financed clean-ups; precluding remediation plans from addressing contamination from non-Superfund sources; limiting the need for otherwise required Federal and state permits; and requiring states to guarantee twenty years' capacity for all their hazardous wastes before they can receive Superfund remedial action money. It is noted that the principal delay in enacting a new and reinvigorated Superfund law relates more to ideological tax policy differences than to issues involving hazardous chemicals, industry responsibility, or human health and welfare.

Neither the current Superfund law nor the pending 1986 amendments to the Act contain a statement of the legislation's principles or goals and objectives. The 1985 Committee Report (S. Rept. No. 11, 99th Cong., 1st Sess., p. 3) accompanying the bill approved by the Senate Environment and Public Works Committee (S. 51) does set forth what is said to be the Act's "major objective," along with four supporting "basic principles." However, much of the controversy and debate which continue to swirl around the Superfund program remain a function of major differences of opinion as to what ought, in fact, to be the goals of this program and on how these goals might be most effectively and efficiently achieved.

No one disputes the need to remedy hazardous substance releases from sites which imminently threaten health and environment. But there is lots of debate over what constitutes an imminent or significant hazard, how much clean-up is sufficient, and what sort of balance should be struck between making the best use of finite clean-up resources and optimizing the clean-up of particular sites.

No one seriously debates the general proposition that those who pollute should pay. However, this principle becomes fuzzy where the "polluting" activities were neither illegal nor recognized as polluting at the time they occurred. It is no easy matter to decide when measures intended to enhance deterrence and accountability end up producing uncertainties so large and potential liabilities so crushing that resistance, delay, and counterattack seem more attractive than compliance and cooperation.

Finally, no one begrudges people the right to be free of unreasonable chemical hazards in their homes and workplaces and the opportunity to play an informed role in decisions which affect their health and welfare. On the other hand, some fear that undue public involvement in the process could paralyze the Superfund program by placing non-negotiable and unmeetable demands for total clean-up in the path of forward motion toward what is attainable.

I will discuss some of the specific elements and provisions of Superfund in light of these issues and concerns which continue to be central features of the debate in 1986 on reauthorization of the Act.

Basic Principles and Objectives

The four basic principles embodied in Superfund, according to the Senate Environment and Public Works Committee, are:

(1) To provide ample Federal authority for cleaning up releases of hazardous substances;
(2) To assure that those responsible for any damage . . . from hazardous substances bear the costs of their actions;
(3) To provide a fund to finance response actions where a responsible party does not clean up, cannot be found, or cannot pay; and
(4) To provide adequate compensation to those who have suffered economic, health, natural resource, and other damages.

Implementation of these principles promotes, in the Environment Committee's view, the accomplishment of Superfund's major objective, which it describes as being: "To provide an incentive to those who manage hazardous substances or are responsible for contamination sites to avoid releases and to make maximum effort to clean-up or mitigate the effects of any such release."

Senator Alan Simpson's (R-WY) "Additional Views" (S. Rept., *supra,* pp. 75–76) make clear that the issues are far from so straightforward. He highlights three issues. First, he cites his "overriding concern," that "Superfund may be asked to do so many things that it will not be doing its greatest task as expeditiously as it might"—namely, cleaning up hazardous waste sites. Second, Senator Simpson voices the concern that the Act's approach to the liability issue "may well come (back) to haunt us," referring to the disturbing indications that "transaction costs" (legal fees, administrative costs, etc.) in some Superfund cases are "approaching or surpassing the projected clean-up costs at sites." And third, Senator Simpson expresses "great" concern over the proposed insertion of "Citizen Suit" language which he sees as posing the potential to disrupt the Superfund program without there having been any showing that there was a need for this new provision in the first place.

Let us now turn to a discussion of Superfund's major issues considered from the standpoint of each issue's significance in accomplishing one or more of the following:

(1) Does it promote or impede the clean-up of sites?
(2) Does it impair or enhance the workability, efficiency, and effectiveness of the Superfund program?

(3) Does it increase or decrease real protections for health and the environment?

Promoting Clean-Up

The dominant thrust of the original Superfund law was to promote and advance the clean-up of sites. It required parties to provide prompt notice of releases (Sec. 103); it established comprehensive governmental response authorities (Sec. 104), enabling the government to take rapid emergency removal action and later recover costs from responsible parties, as well as to select more extensive remedial actions; it provided for abatement actions to address imminent hazards (Sec. 106); it established broad liability exposure for responsible parties (Secs. 107, 302(d)), hopefully providing an incentive to cooperate with the government rather than gambling on being overlooked; it specified broad uses of the Fund (Sec. 111), enabling government intervention to accomplish needed action; and it authorized natural resource damage claims (Secs. 104, 111, 112) both against responsible parties and the Fund to restore damaged natural resources.

By contrast, the pending amendments tend to deal much less with promoting site clean-ups than with either eliminating perceived inefficiencies in the existing process or with expanding the scope of the program.

In addition to some effort to pare back on allowable uses of the Fund (e.g. to pay natural resource damage restoration costs), seemingly in an effort to focus Fund resources on the task of cleaning up sites, only a few of the proposed amendments are really geared to promoting clean-up. They include: the "mandatory schedule" provision of the House bill; provisions aimed at enabling response action contractors (who do the actual clean-up work) to obtain the liability insurance or indemnification necessary for them to operate; and provisions aimed at facilitating the formation of risk retention groups and purchasing groups to acquire insurance coverage in the absence of commercial insurance.

Probably the most controversial of these amendments is the one establishing "mandatory schedules"—an innovation which has been vigorously opposed by the Administration. Although carefully crafted not to establish rigid deadlines for the total completion of remedial actions and preserving substantial administrative discretion to set inspection, study, and clean-up priorities, critics fear that this approach will cause EPA to place excessive attention on bean-counting and meeting schedules and too little on accomplishing high-quality clean-ups and maximizing true health protection. Critics are also concerned that strict timetables, coupled with new citizen suit authority, will cause a proliferation of "deadline" lawsuits resulting in the diversion of EPA Superfund resources to defending these suits.

I find the latter objection unpersuasive. I don't foresee a great flurry of citizen suits in this area; citizen suits are among the least burdensome to adjudicate; and the mandatory deadline provision was drafted to allow deadline suits to be brought very infrequently. Although the concern about "bean-counting" is a little harder to shrug off, the embarrassingly limited number of completed Superfund remedial actions in the program's more than five-year history argues in favor of trying another approach.

Enhancing Program Workability

Fine-tuning the Superfund program to enhance its efficiency and effectiveness has clearly been one of the driving forces behind the effort, beginning in 1984, to amend and reauthorize the Superfund law. How well some of the proposed amendments in fact promote this objective is open to debate, however.

One "reform" in the category of improving program workability is an effort to narrow the scope of the Superfund program by limiting permissible uses of the Fund, presumably in order to focus Agency priorities into the most critical areas. Restricting access to the Fund was a response to frequently voiced EPA assertions that the Agency was capable of managing a Superfund program no larger than $1 billion a year. Whether or not one accepted this argument (and judging by the much larger appropriations approved by the House and the Senate, neither House of Congress did), it was apparent that the magnitude of the Superfund problem far surpasses the availability of resources to address it and that setting priorities was essential.

The House and Senate bills consequently prohibit Superfund response action from being taken to address releases of naturally occurring substances, such as selenium and radon, in unaltered form; releases, such as asbestos, from building structures that result in exposure within a facility; and releases of toxic metals into water supply systems due to deterioration of the system through ordinary use. The Senate bill also prohibits use of Fund money to pay natural resource damage claims in any year that all of the Fund is deemed by the President to be needed for response to public health threats. In addition, the House bill bars responses to releases resulting exclusively from coal mining where response action is covered under the Surface Mine Control and Reclamation Act of 1977. It also bars abatement actions involving the release of registered pesticides and establishes as a defense to citizen suits the fact that a release was specifically covered by a Federal permit.

Additional amendments are aimed at ensuring greater involvement by potentially responsible parties (PRPs) in defining the scope of required clean-up studies and remedial action and in limiting their liability exposure in relation to other PRPs. For example, the House bill allows PRPs to conduct RI/FS studies, which determine the necessary scope of clean-up, in appropriate circumstances; to be notified by the Administrator of their PRP status and of the identity of other PRPs as early as possible before selection of a response action (i.e. to facilitate negotiation among PRPs); to be authorized by EPA, under court-approved settlement agreements, to carry out necessary response actions; and to be provided with information by EPA on the identity of other PRPs and on the nature and volume of hazardous substances at a site, along with a volumetric ranking of these substances, as a stimulant of negotiations among the parties. The bill also allows EPA to enter into covenants not to sue with PRPs (as an inducement to settle), to accept "cash-out" settlements from *de minimis* PRP contributors (to simplify negotiations), and to use arbitration as a means of settling claims. It also reaffirms the right of PRPs to pursue actions for contribution or indemnity against other PRPs and to seek contribution protection (upon successfully resolving their own liability to the government) against potential contribution actions by other parties. It clarifies the authority of the government to enter into "mixed funding" agreements under which the Fund and PRPs share certain clean-up costs. It creates a right to obtain judicial review of Superfund regulators and of intervention by interested parties in clean-up-oriented litigation, including citizen suits, but places some limits on the right to pre-enforcement judicial review.

One of the controversial provisions of the present Superfund law, which the House bill would make even more controversial, is the so-called "fund balancing" provision of Section 104(C)(4). This provision obliges the President to select remedial actions which strike a "balance between the need for protection of public health . . . and the environment . . . and the availability of amounts in the Fund . . . to respond to other sites which . . . may present a threat to public health . . . or the environment, taking into consideration the need for immediate action."

For Fund-financed clean-ups, EPA has relied on this authority to select remedial actions which approach, but fall short of, the level of protection afforded by otherwise applicable Federal requirements to which other clean-ups are subject. The House bill would allow similar Fund-balancing to be applied to privately-financed clean-ups. This amounts to the authority to approve privately funded clean-ups which fall short of normative clean-up standards where the clean-up is deemed disproportionately expensive or technically impracticable from an engineering standpoint, or a lesser level of clean-up is deemed to afford substantially equivalent human health and environmental protection. I confess to some bafflement as to (a) why it was considered necessary to extend a rationale which was designed to conserve a limited public fund to the private sphere; and (b) how it will be possible in practice to judge the practicability of private sector actions using a public sector yardstick.

While this amendment may simply have been intended to promote more cost-effective utilization of Superfund resources, whether private or public, the mechanism adopted could turn out to create a number of new inefficiencies.

Another readily understandable, but nevertheless problematic, provision of the House bill is one which specifies that clean-up standards may be applied only to releases from the concerned Superfund site and cannot be applied to "contamination from other sources." Where other sources contribute to the problem, it is unclear how remedial action is ever to be accomplished—especially since there appears to be no authority provided to use Fund money to make up the difference in cost. If PRPs account for 50% of the contamination, the House bill would allow them to be assessed only half of the clean-up costs—with the rest remaining unremediated unless the state were able and willing to supply the balance.

I will mention one final provision of the House bill which is of interest in this connection. For on-site (in-place) clean-up actions, the bill would eliminate the need to obtain most Federal or state permits. Although a state would still be able to require permits for state standards it had notified EPA of during the RI/FS study, it would lose the right to require permits for any requirements not covered in such a notification and, in any case, would have no more than thirty days after completion of the final remedial engineering design to issue the permit (or the permit requirement would be deemed waived). Moreover, for response actions involving transfer of materials to a facility with a final RCRA permit, no state or local requirement could be applied to the transfer or disposal activity.

These restrictions on permitting and regulation are probably defensible on the basis that bureaucratic red-tape should not be able to slow down the clean-up of an imminent hazard. However, there is no comparable justification for not assuring full substantive compliance. Frequent examples of inadequate or non-existent co-ordination, even among program offices within EPA, don't inspire great confidence that adequate coordination and substantive compliance will in fact occur.

Expanded Protections for Health and Environment

The House Superfund bill devotes extensive coverage to the issues of Emergency Planning and Community Right to Know (Title III) and Oil Spill Liability and Compensation (Title IV). The Senate bill has no counterpart oil spill provision, but it does establish similar (albeit less elaborate) hazardous substance notification and inventory requirements. These hazardous substance emergency provisions were clearly stimulated by the Union Carbide chemical plant catastrophe in Bhopal, India, in December 1984, and by a rash of U.S. accidents involving hazardous chemicals the following summer, many of them centered in the Kanawha Valley of West Virginia. The most controversial Superfund issues in this context have related to whether there is a need for an on-going inventory of operational and accidental releases from chemical facilities (as opposed to simply planning for and reporting of emergency releases); the need to address no more than a limited list of acutely hazardous chemicals (as opposed to also addressing the most dangerous chronic chemical hazards); and where to draw the line between providing necessary information to governmental emergency response officials and public health authorities and safeguarding commercially valuable trade secrets. An expansive House bill, covering both chronically hazardous and acutely hazardous chemicals, was ultimately approved on the House floor by a one-vote margin.

Both bills also eliminate the bias in the present law against "off-site transport," recognizing that in some cases off-site remedies may be preferable to on-site ones. They also encourage the design of removal actions in a way which contributes to efficient performance of long-term remedial action. And they require cost-effectiveness evaluations of remedial actions to reflect long-term as well as short-term costs. The House bill goes further to specify an explicit preference for remedial actions which significantly reduce the volume, toxicity, or mobility of a hazardous substance. These changes should help offset the penny wise, pound foolish tendency to prefer inexpensive short-term remedies which have no lasting effectiveness and wind up costing more in the long run.

Another amendment found in both bills may have unpredicted consequences. Section 104(c)(3) bars Federal remedial actions at Superfund sites unless the host state first agrees to assure the availability of a hazardous waste disposal facility suitable to accomplish any required off-site treatment or disposal. The amendments would require states to guarantee adequate capacity and access for the treatment or disposal for *all* of that state's hazardous wastes for the next twenty years. Although this approach may give useful impetus in some cases to the development of sorely needed hazardous waste management capacity, it could have a negative "double-whammy" impact in other cases. That is, less responsible states which are unable or unwilling to make provision for managing their hazardous wastes will be penalized by not having their Superfund sites cleaned up. But their citizens will be penalized twice: once, by the neglect of their state; later, by the retribution of the Federal government. I have some trouble with an environmental sanction which leaves the environment worse off when it's invoked than it was before.

Both bills also strengthen the controls on Federally-owned Superfund sites and create a new citizen suit authority. I view both of these as positive steps, likely to stimulate more good than harm.

The bills also make somewhat greater provision for citizen and state participation in important site-specific Superfund actions and decisions.

Conclusion

It could probably be fairly said that there is something for almost everyone to dislike in the pending Superfund bills. And students of government and public policy will be horrified at the complex and convoluted monstrosity wrought by the world's greatest deliberative body.

I believe Superfund will be reauthorized in 1986 because the alternative is simply not an option. But, I am not optimistic that it will be reauthorized much before the November elections nine months from now. A delay that long would have catastrophic consequences. A large proportion of EPA's specialized Superfund staff would have to be fired. The contracts on which the momentum, and much of the institutional memory, of the program depend would have to be terminated. The phased sequence of site studies, alternatives, evaluations, remedial planning, and construction work would be thrown into chaos. And the inexorable seepage of deadly chemicals would continue unabated.

It would be ironic and unfortunate indeed if, after coming to grips with most of the thorny technical details of program implementation, the effort to enact a new and reinvigorated Superfund law were to founder over idealogical tax policy differences having nothing to do with hazardous chemicals, industry responsibility, or human health and welfare.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 31–36, March 1986

Responsible Toxics Management: The Silicon Valley Experience

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Introduction

What better place to seek balance between technology and the environment than in Silicon Valley? Here is the heart and soul of modern American technology in this post-industrial age. Here, too, in the early 1980's, we learned that production of electronics equipment and semiconductors and computers has serious environmental problems. And here too, in the mid-1980s, we see an innovative attempt to find the path to responsible toxics management—a pattern of procedures and decisions and expenditures that balance toxic risks to public health; growing public credibility in both government and industry; long-term availability of groundwater resources; and the continued vitality of the electronics industry and the Santa Clara Valley's economy.

What lessons does this experience hold for the rest of America?

A Clean Industry

Part of the subsequent problem of public fear over toxic risk in Silicon Valley has its roots in our own expectations. High tech was different. Silicon Valley had it; every place else wanted it. This was to be the magic saviour of America's rusting old industrial base—our means of transition from the past into the future.

And high tech was supposed to be a *clean* industry. We all fell victim to the rhetoric of "clean rooms," seduced by the imagery of campus-like industrial facilities in contrast to traditional factories with their tall stacks belching smoke. We truly believed that high tech was different.

When we awoke to the contrary reality, we were confused and angry, full of distrust. Risks to health from environmental toxics may indeed be very low in Silicon Valley—at least outside the workplace. Compare Silicon Valley's ambient toxics to New Jersey or Galveston or Niagara Falls or Los Angeles; they're lower, by far. But such risks are now seen to be present in the Santa Clara Valley—they are *not* zero. So the people of Santa Clara County in 1981 suddenly felt that they had been had. Their normal, human reaction was thus to act, even to over-react.

"Here the Smokestacks Point Down"

In December 1981—December 7, ironically—we all learned that high tech in Silicon Valley was *not* so clean. And we began to use the phrase: "here the smokestacks point down." A massive leak of industrial solvents from an underground waste tank of the Fairchild Camera and Instrument Company, in San Jose, had leaked into nearby groundwater: 60,000 gallons of TCA, TCE, DCE . . . a whole toxic chemical soup. This groundwater was used for drinking. Almost exactly half of the valley's 1.4 million residents drink groundwater. Several wells of the nearby Great Oaks Water Company, serving some 65,000 people, were found to be contaminated. Great Oaks Well #13 was highly polluted, and had to be closed immediately.

Though these wells were closed, panic was loosed on the community. How much health damage had been done? A subsequent State of California epidemiological study in the Los Paseos neighborhood, across the street from the now-closed Fairchild factory, found statistically-significant excessive levels of birth defects and miscarriages during the period of undetected well contamination (when people were actually drinking this contaminated water). Unfortunately, the scientists could not prove the contaminated water was the cause of these tragic health damages, since other too-high levels were found in a control group nearby where people drink water from other, demonstrably-clean wells. Were the toxics at Los Paseos and nearby in the air? Was the damage due to occupational exposure? More studies are now underway, but the fear and anger have spread from 1981 on.

As we looked elsewhere, we found other leaks—lots of contaminated groundwater. The huge IBM complex, near Fairchild, had a huge plume of TCA, Freon, and other chemicals. Yet, when industry later removed many of these tanks, at IBM and all over the valley, around literally scores of groundwater contamination incidents, nearly all of these tanks were found to have full mechanical and structural integrity. The groundwater contamination had apparently come from spills onto the ground: "sloppy housekeeping." Tank truck drivers were under such pressure to deliver *pure* solvents, for example, that they rinsed their hoses onto the ground to eliminate road dirt and even water vapor. What harm could it do? We have learned since that even just a few ounces of solvent can produce a huge groundwater plume measured in parts per billion.

As we looked, we found—and all the familiar names were there: Fairchild and IBM, HP and Intel, AMD . . . all of them. By January 1986, we had documented some 70 episodes of groundwater contamination from industrial solvents in Silicon Valley, plus 36 from other industrial compounds and 540 from the 6,000 fuel tanks. We are now discovering 5 to 10 new episodes per day as we look intensively through groundwater monitoring.Some drinking water wells have had to be closed. Others are still in service, pumping water with low, but detectable levels of organic chemical contamination. EPA has proposed 19 sites in Santa Clara County for inclusion on Superfund's National Priority List—more sites than in any other county in the U.S. Without doubt, we have a significant environmental problem in this technological center. And we have a public perception of environmental risk that far exceeds what anyone would have predicted.

Initial Responses

In Santa Clara County, the extent and the quality of response to these environmental problems have been astounding, by comparison to anywhere else in the U.S. This response has come in a balanced manner from government, industry, and the general public. Perhaps this balance—in tune certainly with Charles Lindbergh's philosophy of a balance between technology and environmental quality—helps explain our relative success, and provides a basis of optimism for future success in responsible toxics management—another prime Lindbergh value.

Government has responded at all levels, with some success . . . and some confusion. The electronics industry has spent in excess of $110 million already on cleanup—identifying plumes, groundwater extraction, tank removal—and on prevention—installing new tanks and monitoring systems.

In 1983, local governments throughout the area combined to formulate a powerful new Hazardous Materials Storage Ordinance. Based on work by an ad hoc task force composed of fire marshals, city managers, industry representatives, environmental and labor group leaders, elected officials approved a model ordinance. This ordinance was adopted within one year for implementation in all 15 municipalities in the county. The ordinance sets strict standards for control of all underground tanks, and of above-ground storage of all hazardous materials. Control over underground tanks spread statewide in California in 1984, based on large measure on the experience in Santa Clara County. In late 1984, the national hazardous waste regulatory law (RCRA) was amended to include a new section on regulation of underground tanks across the country. In 1985, controls on above-ground storage of hazardous materials also spread statewide in California, again drawing on the Santa Clara experience.

As part of implementing the ordinance, firms have drilled literally hundreds of groundwater monitoring wells—thereby finding more and more plumes of contamination. Cleanups are underway, inadequate by some perspectives but astounding by others.

In early 1984, in the midst of all this activity, EPA began a special new cross-media risk assessment project: the Integrated Environmental Management Project or IEMP. This effort is designed to compare toxic risk quantitatively—risk from different chemical pollutants, indifferent pathways (drinking water, air), and from different sources. This project lays the basis for a new style of responsible toxics management, first in Santa Clara County and ultimately nationally. Based on a local risk assessment, priorities can be set for decisions on regulating and managing groundwater, THMS, air quality, and so on. EPA's draft IEMP report issued in September 1985 found risk from chlorination of surface water supplies of drinking water, and from air toxics, to be generally about the same as similar risks in other urban areas: risks were quite small, though noticeable. Risks from exposure to contaminated groundwater in Santa Clara County were found to be much smaller than risks from air toxics or surface water supplies. That is, groundwater contamination in this area, and perhaps elsewhere, does not necessarily equal drinking water risk. The two are related, but not identical.

How can this be? With hundreds of toxic leaks or spills in the Silicon Valley, why is public exposure to contaminated water supplies—and therefore risk—so low?

In essence, three factors are at work. First, several actions already are being taken by government and by industry to intervene in the risk/exposure pathway to protect the public. Regular monitoring takes place at all 300 drinking water wells serving large water systems. The county contains 19 such large public systems, which together serve the overwhelming proportion of Santa Clara's residents. Their wells have been monitored at least quarterly since 1985 to detect the presence of organic chemicals. Wells located near known plumes of groundwater pollution are monitored monthly or even weekly. Since risks to health (e.g. cancer) are associated with chronic, long-term exposure to these kinds of chemicals at levels typically measured at a few parts per billion, regular monitoring provides an essential protective shield. If significant contamination is detected, the well can be closed or its water treated prior to use. A pilot program to monitor hundreds of private water supply wells began in 1985.

In addition, control and cleanup of existing plumes of groundwater contamination help lessen risk. Groundwater monitoring wells—IBM alone now has more than 300—define the spread of each plume and determine its levels of contamination. Extraction wells remove contaminated groundwater and purge it of its volatile organic chemical contaminants, occasionally by carbon filtration but normally by aeration in storm sewers. The water, minus its contamination, is then discharged into San Francisco Bay. Industry has already expended in excess of $100 million on all of these cleanup actions since 1981. In contrast, federal Superfund in 1984 allocated a $1 million grant to accelerate groundwater cleanup. As of early 1986, however, this money was essentially still mired in the bureaucracy, not yet contributing substantially to any cleanup.

Second, the groundwater aquifers in Santa Clara are complex, and provide a further basis for protection of public health. To simplify, in much of the valley a thick layer of clay divides shallow aquifers (where the contaminant plumes exist) from the deeper aquifers (from which all of the public supply wells draw their water). In sum, the leaks are shallow but public water supply wells are deep. Geography and hydrogeology do matter. Unfortunately, several thousand abandoned agricultural wells pierce this clay layer, potentially allowing some contaminants to reach the deeper drinking water supplies. Facing this challenge, the independent Santa Clara Valley Water District allocated $800,000 to begin to identify the old wells, and to seal them to preclude the downward migration of the chemicals.

Third, when cancer is involved, the best available science tells us that dilution lessens risk. As opposed to conventional kinds of air and water pollutants, and to noncancer health effects from toxics, we believe that no exposure thresholds apply to cancer risk (the so-called "one molecule theory"). That is, exposure to a small amount of a carcinogen is bad, and exposure to more is worse—with no threshold level below which zero risk/absolute safety apply. Thus the dilution of these organic solvents into literally billions of gallons of pristine water in underground aquifers lessens risks to public health. Since drinking water wells typically pump simultaneously from several different levels, they further dilute contaminated water with further pristine water. As a result, the gap between groundwater contamination and drinking water risk—a real gap, if one not always perceived by a frightened public—diminishes further with dilution.

Does all this warrant complacency? No. Definitely not. Several vulnerabilities and issues are now emerging to dominate the agenda for responsible toxics management:

(1) Private wells are doubly vulnerable. They are shallow (where contaminant plumes are found), rather than deep. And except for the county's pilot program, they are unmonitored rather than monitored. Santa Clara County in 1986 is mounting an effort to monitor over 1,000 of the 5,000 or so private wells as a way to lessen this vulnerability.
(2) The underground tank and above ground storage ordinances covering industry's management of its hazardous materials need to be fully imple-

mented to protect the public. Given the fragmented situation with most city fire department's operating their own independent programs, implementation remains somewhat unknown. As a result, the Santa Clara County Intergovernmental Council has devised a questionnaire to determine the status of ordinance implementation in each jurisdiction.

(3) Classic resource issues are beginning to become more evident in responsible toxics management. Most strikingly, the groundwater cleanup extraction wells are presently pumping, and discharging to the Bay, some 19 million gallons per day of water (once the contaminants disperse to the air, indeed it's perfectly pure water). This process was derisively termed "pump and dump" in a late 1985 House of Representatives Committee hearing in San Jose. This is an immense volume of water. In a state where "water equals politics", such discharge is unlikely to be tolerable perpetually. Yet cleanup of contamination by extraction wells inexorably leads to such results when the contamination is present in only 5 or 10 parts per billion.

(4) We need to come to grips with how clean is clean? (Or how safe is acceptable and affordable?) Can we devise a process to determine that level of toxic contamination of groundwater (or air) beyond which it is technically infeasible or economically unacceptable to proceed further with cleanup actions? And will a frightened citizenry accept such a determination (given the zero-threshold concept of cancer risk)? Again, balance is essential—but frustratingly elusive. Work underway in the Santa Clara cleanup in 1986 should provide the nation's first, fumbling answers to this conundrum.

(5) Who pays for cleanup? Polluters, state tax payers, federal Superfund?

(6) Managing the aquifer—How can we deal with toxic contamination, and cleanup, of the groundwater basin as a whole rather than simply chasing hundreds of plumes and then pumping dozens of them through extraction wells?

As noted, we're beginning to come to grips with these issues:

—private well monitoring
—Storage ordinance status . . . pressing for data through the questionnaire studies of drinking water
—treatment/chloramination/risk to the public
—exploring creation of a fund for overall aquifer management rather than plume chasing alone.

The battle ahead pits pursuit of standards against the values of nondegradation, and frames the debate over responsible toxics management in the face of continuing scientific ambiguity standards offer clarity to industry and the public. Unfortunately, they tend to mask the fact that cancer risk exists below standards, at any level of exposure to carcinogens. Standards for individual chemicals mask possible dangers from synergism. And a cynical angry public is *not* prepared to allow polluters to pollute groundwater—"oops, sorry"—so long as they don't violate established health-based standards. So the issues are not risk, per se—but equity and distrust and power and "who pays" decisions—classic political economy.

Can we achieve zero exposure and zero risk (true nondegradation)? No way! This is simply impossible. But this remains the key public policy *goal,* and the basis for rebuilding government credibility. Three tests emerge in pursuit of this goal:

—technical feasibility
—costs of cleanup
—benefits in risk reduction, resource conservation, and achievement of other values

In sum, a federal paradigm for risk assessment along the lines of the IEMP—plus standards—can be combined with local authority to make local decisions about acceptable risk. An informed public can openly weigh the benefits—and costs—of toxic cleanup. Standards can be used to ensure adequate public health protection nationwide, while local areas can go further in both prevention and cleanup. As a result, a balance between risk and cost, safety and equity can be accomplished. That is, responsible toxics management can be achieved.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 36–43, March 1986

From Conflict to Cleanup: The Clean Sites Approach

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ABSTRACT

Although the Superfund law was enacted specifically to provide a mechanism for promoting the cleanup of the nation's hazardous waste sites, many factors still hindered the site remediation process. Some pertained to the complexity of implementing the new program while others related to the nature of the problems encountered in defining specific site characteristics and in identifying and implementing proper solutions. Clean Sites, Inc. was created in response to a study which identified specific needs in the site cleanup process. This not-for-profit organization has as its sole purpose, the facilitation of hazardous waste site cleanups by encouraging and assisting private party cleanup efforts. By providing negotiation and settlement services, technical reviews and analyses and project management skills, Clean Sites is able to assist in the cleanup process from beginning to end. Specific benefits which CSI can provide to site cleanups are discussed. Among these are cost and time savings to both responsible parties and the government and independent and unbiased assistance which assures that all parties concerns are addressed. After nearly two years of existence, Clean Sites has made significant progress at many sites. Current activities and plans for future activities are summarized.

In the past, our nation has carried out and even condoned some hazardous waste disposal practices that we all would now consider bizarre. Over time, we have improved, but storage, handling and final destruction or disposal practices still leave much to be desired.

In response to growing public concern about the environmental and Public health threats posed by abandoned hazardous waste disposal sites found in every part of the United States, Congress passed, in 1980, the Comprehensive Environmental Response Compensation and Liability Act, popularly known as "Superfund". The creation of Superfund came amid high hopes that it would be a major step forward in providing protection against the nation's thousands of abandoned hazardous waste sites. In particular, grave concern existed concerning the threats such sites pose to surface water, ground water, and public health.

Not surprisingly, hazardous waste cleanup has proven to be a far larger and more complicated task than many imagined in 1980. The difficulty encountered reflects in part the fact that the problem of abandoned hazardous waste site cleanup developed as a consequence of many years of ignorance, neglect and, in some cases, intentional wrongdoing. The hazardous waste problem is also a result of the technological revolution that improved the standard of living for Americans but also had some unintended consequences for both the environment and public health.

Ironically, the problem also reflects a dramatic improvement in scientific ability to detect minute quantities of potentially hazardous substances—down to parts per billion and even lower.

These improved capabilities leave the scientific community struggling to define the precise health and environmental threats—both short and long term—from minute quantities of hazardous substances. In turn, the U.S. Environmental Protection Agency (EPA) is presented with a very difficult job: proceeding with waste site cleanup at a time when new research is changing the nation's understanding of the nature of the requirements for cleanup.

EPA estimates there are about 20,000 potentially hazardous waste sites in the United States, and that as many as 2,000 or more may be serious enough to warrant placing on its Superfund National Priorities List (NPL) of the nation's worst sites (see Figure 1). It may cost the government nearly $23 billion to clean up sites on the list. (Other estimates of both sites and costs are even higher.) Currently, about 850 sites have been placed on the list.

Consider the Superfund process. After a site has been placed on the NPL, it must be determined whether the site will move toward cleanup through government enforcement action, or voluntary action involving the parties responsible for pollution at the site (see Figure 2). When the government decides a cleanup is needed to protect public health and the environment, the potentially responsible parties may negotiate a settlement among themselves that paves the way for them to conduct a governmentally approved cleanup.

LONG-TERM CLEANUP PROJECTIONS

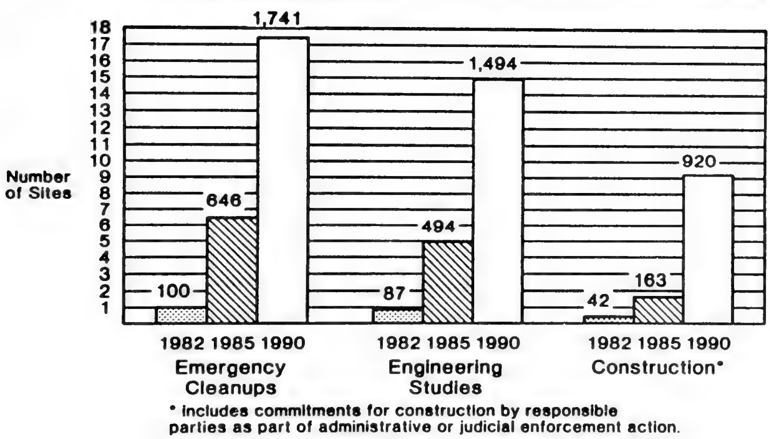


Fig. 1

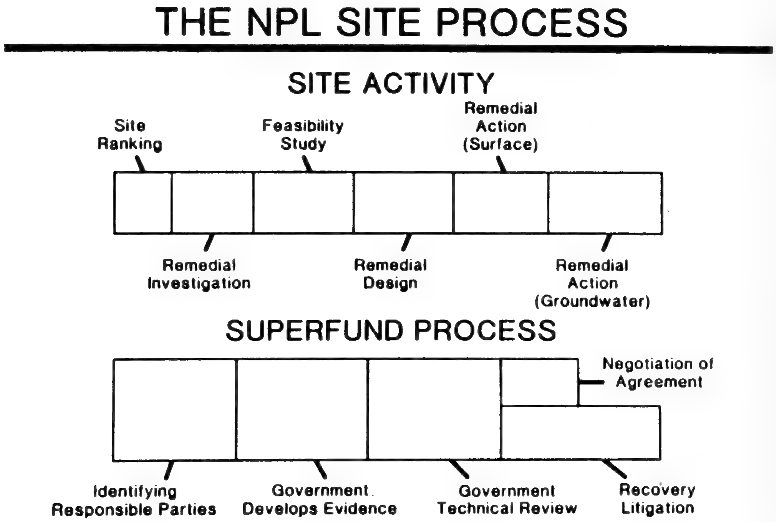


Fig. 2

If the responsible parties do not respond in a timely manner, EPA may undertake the cleanup, and then later sue the responsible parties to recover funds spent by the government.

It is important to note that the government has a powerful enforcement tool at its disposal, "joint and several liability." This means that any single individual or company that dumped hazardous substances at a site can be held liable for the bulk of the cleanup costs.

In short, the Superfund law, and general government policy (as well as recent court actions) all work to encourage voluntary hazardous waste site cleanups wherever possible. Moreover, a basic sense of fairness makes it seem reasonable that the parties contributing to the problem should also contribute to the solution.

Progress has, however, been painfully slow. Federal and state officials involved in this issue report a common dilemma. Even while the general public demands vigorous Superfund activity there is significant local opposition to many site cleanup plans. Another impediment to action is the highly complex nature of cleanup regulation, often involving several different layers of government.

This situation is paralyzing action at many sites, particularly at multi-party sites where there may be scores or even hundreds of potentially responsible parties, or PRPs. Such parties potentially responsible for waste at a site can include those who produced the waste and those who transported it, as well as site owners and operators. They can include a wide range of private individuals, corporations, and agencies of local, state and federal government.

It was amid this background that Clean Sites was established in May, 1984, as an independent, non-profit corporation with a single objective: to help accelerate the cleanup of hazardous waste sites by encouraging cost-effective, voluntary private party cleanups. How did this happen?

In the summer of 1983, a group of corporate and environmental leaders and former public servants gathered under the auspices of The Conservation Foundation to examine the obstacles blocking voluntary cleanups and to try to determine how the process might be expedited. This group investigated several sites where remedial actions were being planned or were actually under way. Their goal was to find out which approaches worked, which did not, and whether experience could lead to more practical solutions.

The panel concluded the United States lacked a single, comprehensive mechanism that is specifically designed to adequately manage the cleanup of individual hazardous waste sites over the long term. They discovered that the skills that were missing from cleanup actions were not so much technical skills as they were managerial capability properly focused on the various pieces of the problem. Specific questions of legal liability were also found to be significant stumbling blocks to agreements. More importantly, the panel found what was missing was an equitable and effective process that would encourage responsible parties to allocate cleanup costs among themselves through negotiations.

Because the group was searching for new answers to hazardous waste cleanup, it looked for solutions outside the bounds of government and taxpayer funds. The study panel suggested setting up a new mechanism to reduce the types of conflict found at sites, a mechanism that would work specifically to enhance collaboration among the parties responsible for the waste and to facilitate cooperation among all the involved parties. This resulted in the formation of Clean Sites, Inc. (CSI).

Because any new institution that proposes to play an active role in such a complex process can be misunderstood, it is important to emphasize what Clean Sites is and is not.

* CSI is an independent, non-profit, nonpartisan organization committed to protecting public health and the environment (see Figure 3). We depend on financial support from foundations, corporations, organized labor and private citizens. We also depend on businesses, public interest groups and academic institutions for donated personnel and expert advice.
* CSI is a way to extend EPA's effectiveness in site cleanups. CSI is a facilitator to help the government, and the parties potentially responsible for pollution at a site, accomplish settlements that are in the public interest. CSI is structured to enter the cleanup process along its entire spectrum. Figure 3 shows the number of sites at various entry points for CSI as of late 1985.
* CSI is an additional source of professional and technical expertise to provide guidance and interpretation concerning proper cleanup, and an independent source of project management talent to direct the agreed-upon cleanup.
* CSI is NOT a replacement for, but rather a complement to, the EPA. CSI will not substitute for government in deciding what is the proper level of cleanup.
* CSI is NOT a replacement for a strong Superfund law. In fact, CSI's success will depend on an amply-funded Su-

CSI POINTS OF ENTRY

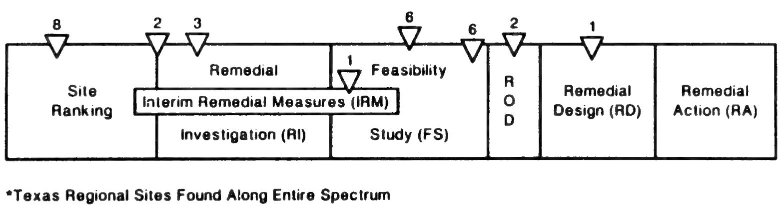


Fig. 3

perfund backed up by strong and consistent federal enforcement activities that provide the essential incentives to voluntary cleanup.

* CSI will NOT be a source of funds to pay for site cleanup—potentially responsible parties and the government must be that source.
* Finally, let me emphasize that CSI is NOT the sole answer to the nation's hazardous waste problems. We are now involved in various kinds of active work at 36 sites. Our ultimate goal is to be active at 60 sites by our third year of existence. Yet, even this level of effort cannot address the majority of sites the nation hopes to clean up during this period (see Figure 4).

In effect, Clean Sites is a mechanism to focus additional resources on the hazardous waste problem. CSI provides a channel for bringing new resources together, and targeting them on specific projects that the government might not otherwise be able to address in the near term. In doing so, CSI can help shorten the time between the identification of a problem and the implementation of its solution (see Figure 5).

We believe that the models and methodologies we are using and developing at Clean Sites can be extremely effective in facilitating private party cleanups. CSI can save the parties substantial time and effort in the legal and administrative activities needed to achieve a governmentally approved, environmentally sound settlement (see Figures 6 and 7).

To help achieve such settlements, CSI will provide the means to facilitate potentially responsible parties coming together. CSI can provide private conference facilities and teams of negotiating experts at the conference facilities in our Alexandria, Virginia, headquarters. Of equal importance, negotiations are also taking place at other appropriate locations, often in the areas where the sites are located.

Remedial cleanup projects done quickly will not replace cleanups done well. Affected citizens, industry, and government are all concerned that remedies employed to rehabilitate a site must protect the public health and environment. CSI has available to it—both in-house and through consultants—a technical review and compliance capability that is both independent, and of the highest quality. This ensures that remedies meet the standards of a changing technology.

CSI can implement approved cleanup remedies through its project management teams. All projects are subject to stringent

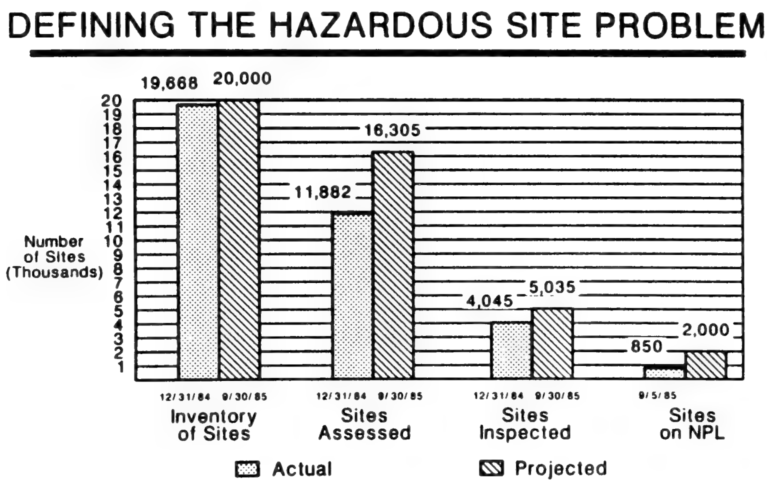
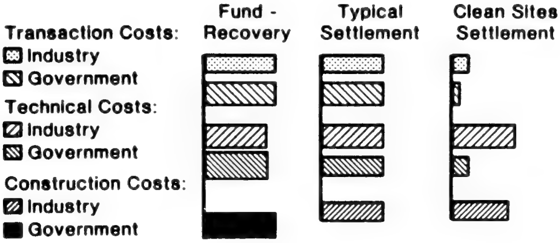


Fig. 4

CAN CLEAN SITES REDUCE THE COST OF CLEANUP?



With the Conservative Assumption That Transaction Costs Are Amounting to One Half of the Total Costs of NPL Sites

Then Full Clean Sites Involvement Can Help Achieve These Savings:

	Fund	%Saved	CSI Savings
Transaction	50%	50-90%	25-45%
Technical	15%	40-70%	7-10%
Construction	35%	20-40%	7-14%
Total	100%		39-69%

Fig. 5

quality assurance/quality control requirements, as well as other standards.

Overall, CSI is becoming an increasingly effective repository of settlement, managerial, and technical expertise—allowing the knowledge gained through several cleanups to be stored in one institution, digested, used again by us, communicated for use by others.

At the root of CSI is the assumption that the private sector has developed the experience to carry out complex projects in a safe, well-managed and cost-effective manner. Industry has many resources—managerial as well as material—that often permit it to accomplish projects at less cost but with the same quality as the public sector. In the waste site cleanup process, this can mean savings in construction, technical and transaction costs (see Figures 5, 6, and 7).

CSI can also reduce the cost of getting an approved settlement for potentially responsible parties. These transaction costs can mount up quickly and contribute little to getting the site cleaned up. Potentially responsible parties can waste millions of dollars duplicating each other's efforts to attribute cleanup cost liability.

Conserving public resources is equally important. Agencies face heavy demands on their personnel and financial resources. Using government funds to pursue potentially responsible parties through litigation is not the most cost-effective or quickest path to cleanup, especially when settlement is possible.

Allocating costs for site cleanup is a difficult task requiring good faith negotiations among all the responsible parties. Issues of fairness, technological and scientific feasibility and economic viability become major factors during discussions. Potentially responsible parties will be reluctant to undertake voluntary cleanups if they do not believe the outcome of negotiations will be fair.

CLEAN-UP AND TRANSACTION COSTS

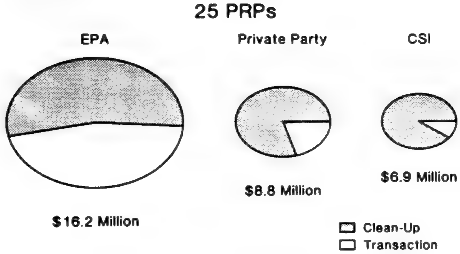


Fig. 6

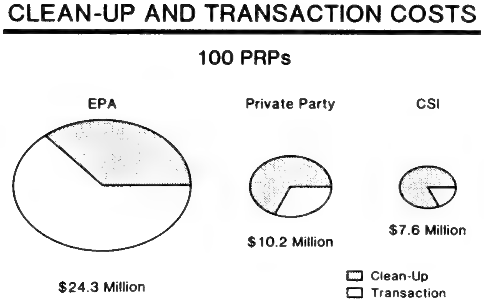


Fig. 7

CSI can offer a more cost-effective procedure that allows responsible parties more involvement in the remedial solution at a site, while still meeting government standards. CSI, in providing a neutral territory and skilled negotiators, can help assure affected parties their views will be heard and addressed.

As I've already discussed, many site cleanups are lengthy, costly, and complex projects; some are more simple. The basic Superfund process outlined by the EPA is a multi-step one (see Figure 2).

* If a site is thought to pose a long-term threat, it is given a *hazard ranking score,* based on its threat to the surrounding population and its ground water, surface water, soil, and air. If a site is judged sufficiently hazardous, it is placed on the National Priorities List.
* Any site cleanup must include comprehensive scientific and technical studies to determine the full facts and best means of proceeding. The *remedial investigation* involves a field study that determines the nature and extent of the contamination. The *feasibility study* then evaluates the information obtained in the remedial investigation in order to determine the proper, cost-effective response that assures a site cleanup that adequately protects public health and the environment.
* The next step, the *remedial design,* establishes the engineering plan necessary to remedy threats or potential threats from a hazardous waste site.
* The *remedial action* is the physical work at the site involving implementation of the appropriate cleanup options.
* If *ground water* is threatened, long-term monitoring, pumping, and treating of that water may be necessary.

In such a complex situation, effective, positive interaction among technical experts, responsible parties, government agencies and affected citizens will characterize successful cleanups. Carrying out this sort of project is a challenge requiring advanced managerial skills and techniques. CSI is working closely with leaders of industry, government and public interest groups to bring these skills to bear on solving the hazardous waste problem.

The sites we are now working on cover a wide range of activities. Whether it is working on cluster settlements, allocation mechanisms, remedial studies or actual removal and incineration of wastes, we believe CSI is showing its value to all parties concerned about hazardous waste.

Credibility can be a major stumbling block to public acceptance of particular site remedies. For the public to believe that a site is being cleaned up in the best way possible, citizens must be assured that effective measures are being taken to protect public health and the environment. In this kind of situation, a two-way flow of information is essential to build this credibility.

The "public" affected by hazardous waste sites is broad. It includes community residents, responsible parties, government officials, public interest groups, and the news media. To be responsive to these diverse groups, CSI has a Public Accountability Office that is working with the entire CSI staff and reports to the president and executive vice president.

It wasn't too long ago that we at CSI

talked about our organization as a "concept." CSI is no longer just a concept. We are building models for negotiation, arbitration, and allocation that, we believe, will significantly advance the state of the art in waste site settlement development.

We are receiving site suggestions from a variety of affected parties and have been asked to work at 130 sites. The invitations have come from industry, government, and community groups. Since we clearly cannot work on that many sites, the challenge we face is to carefully screen and select them. At present (February 1986), we are active at 20 site situations, comprising 36 individual sites.

Three site agreements are completed; five are pending before EPA. One cleanup will be complete by spring; other interim remedial work is underway.

We are working with 1,200 responsible parties. This covers 15 industrial sectors, all levels of government (local, county, state, and federal) and non-profits (universities and hospitals).

CSI evaluation of information has been the key to allocations at 24 sites. Thorough, unbiased evaluation, sometimes utilizing specially created computer data base systems to handle thousands of documents, is critical to derive allocations.

CSI hopes to provide benefits to society far beyond our direct involvement at sites. We plan to accomplish this by developing specific models of settlements and remedial cleanup activities, and by showing the way toward a consensus-based environmental policy for the 1980s that is less adversarial and more cooperative in nature, but that still protects the public interest. This means building relationships with and among citizens, corporations, all levels of government and other concerned people. We have made significant progress already and expect to continue and broaden our efforts in the future.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 44–48, March 1986

Waste Reduction: Industry's Challenge

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ABSTRACT

Industry has a challenge to both society and its stockholders to minimize the generation of waste. There are both short and long term benefits which result in reduced costs and the potential for environmental problems. The 1984 Resource Conservation and Recovery Act Amendments provide increased incentives to minimize waste. However, the economics of good waste management practices will continue to drive the effort. Several examples within Du Pont are cited which demonstrate how advances in technology have permitted better control of the manufacturing process. The need for high standards for operations, housekeeping and training are also shown to be key elements in a successful waste reduction effort.

Du Pont's organizational structure is described as it relates to environmental policy and implementation of programs such as waste minimization. It incorporates engineering, marketing and research functions to identify the best methods to manage wastes. The government's obligation to design regulations which encourage reuse and recycle is also highlighted.

It's a pleasure to be here today and to have the opportunity to participate on this panel. The challenge industry faces in reducing waste centers upon optimizing, for the common good, the use of the limited resources that we traditionally devoted solely to the production of goods and services. On a May night in 1927—about halfway across the North Atlantic—I'm sure that optimal use of a limited resource, fuel, must have been uppermost in the mind of Charles Lindbergh. Like him, if we in industry are to accomplish our mission of reducing waste in the most effective manner, we must keep optimal use of resources continually in mind. This frames the principal challenge we in industry face as we investigate ways to reduce generation of waste.

The challenge to reduce the amount of waste generated is directed by the society in which we operate and by our stockholders. Industry's responsibility is to both and they are of equal importance.

Both sectors can benefit from waste reduction. Stockholders benefit through reduced production costs and a reduction of potential future liabilities. These increase both short and long term profits. In short, *waste minimization is simply good business*.

Society benefits in several ways. The potential for both short and long term environmental problems is reduced. And, we are able to more efficiently use our limited natural resources. Finally, reduced waste will inevitably lead to lower cost for products, and thus, a higher standard of living for all Americans.

Considering these benefits, it should come as no surprise that waste minimization is not new to industry. However, to be candid, recent government regulations have added an incentive to industry's efforts in this area.

In 1984, a Federal law, the Resource Conservation and Recovery Act, established for the first time a national policy for waste management. The waste minimization section of this law can be compared to the energy conservation measures of the early 1970s. The severe limitations on land disposal practices increases the economic incentive for waste minimization. However, it is the considered opinion of most experts who are following the major developments in waste minimization policy, that in the long term it will not be the law, per se, that will fuel waste minimization efforts, but rather the basic economics of good waste management practices.

My intent here is to provide some history and background, to develop the criteria for an effective waste reduction program, describe how one company—Du Pont—approaches the effort, and, finally, cover some of the barriers which tend to inhibit this activity.

Reviewing waste management from a historical perspective, past minimization efforts by industry were driven primarily by economics. It is, after all, quite basic to expect the most efficient producer of a given product to have the best competitive position and to be the most profitable.

Continuing research efforts devoted to achieving less waste have been an ongoing activity in competitive industries such as the chemical industry. A classic example of this is illustrated by the manufacture of polyethylene. Developed about the time of World War II, this polymer found immediate application as an insulating material for electrical cables. At the time, manufacturing costs were high due to problems associated with a new process and product yields from the raw materials were only 10–20 percent. The selling price exceeded one dollar per pound.

Research to improve the manufacturing process led to significant yield improvements over the years. Today, unreacted raw material is recycled and overall yield of polyethylene has increased significantly. Yields typically exceed 95 percent.

Naturally, the expected happened. Waste was reduced; cost and, in turn, selling prices decreased. End uses multiplied and the benefits to society expanded. Today, uses of this material are vast and it sells for about 35 cents per pound. This equates to approximately 7 cents per pound in 1947 dollars, a reduction of roughly 93 percent over the past four decades.

This is the most effective method of waste management, i.e. improving the manufacturing process so that what was once waste is now productive end product.

Advances in technology leading to waste reduction have not, however, been limited to process improvements. Some of the most dramatic advances have been made, and continue to be made, in the systems used to control waste generation itself. Advances have been possible in this area primarily due to the use of improved instrument systems, among them computers.

While the use of large computer systems is costly and complex, these barriers are continually being reduced with the rapid advances being experienced in the electronics industry. Today, small microprocessors are relatively inexpensive, easy to install, and can be tailored to the needs of small operations. They continue to hold large promise in our efforts to reduce waste generation.

Computers enable us to sample conditions, compare the results with other parameters and make needed corrections with much greater sophistication than in the past. The net result is more precise control of the manufacturing process; and, therefore, reduced energy requirements, better raw material utilization, and better product quality. All of these ultimately lend to more pounds of product per pound of ingredient and less waste generation.

A good example of this technology applied to a real world problem is provided by our LaPorte, Texas, facility. Installation of a microprocessor on the steam boilers at that site has enabled us to reduce the amount of wastewater generated by over 12 million gallons per year. The system is simple and reliable. Maintenance needs are minimal.

It is important to defuse the impression that waste reduction is solely a result of technological change. Equally as important are high operating standards, good training and good housekeeping practices. In this area, opportunities for waste reduction are numerous. They include careful cleaning of process equipment to reduce quantities of waste, improved techniques for loading and unloading of equipment to reduce contamination, and proper connecting and disconnecting of hoses and lines to reduce spills and prevent quality problems. These become accepted practices only if they are important to management.

Despite the obvious economic incentives, waste minimization programs do not develop automatically. A commitment from senior management is necessary. A policy must be developed; sensitivity and knowledge of the issue must exist at all levels of the organization. A program must be established by those responsible for each operation. Goals must be set so that performance can be measured. Finally, an audit system must be established to determine progress and, the progress must be communicated throughout the organization.

Within the Du Pont Company, waste minimization efforts are centralized in appropriate committees of the Executive Committee of the Board of Directors.

The two most prominent committees within Du Pont are the Environmental Quality Committee (EQC) and the Manufacturing Committee (MC). Corporate policy for safety, health and environmental affairs is established by the EQC and implementation of this policy is accomplished through the Manufacturing Committee. The latter is comprised of the heads of the manufacturing operation from each industrial department. A subcommittee of the manufacturing committee—the Hazardous Waste Advisory Committee (HWAC)—has been established for the purpose of coordinating activities associated with hazardous waste. Two principal objectives of this group are to: 1) to provide guidelines for waste reduction efforts and, 2) to insure that innovative approaches are communicated throughout the company. In addition, the HWAC is working to define corporate waste reduction goals and techniques for measuring and communicating progress toward those goals. This group has the backing and commitment of the highest levels of management within the company. This organizational commitment results in awareness in all the sectors of the company and highlights the importance of waste reduction.

We use our engineering, marketing, and research functions to identify the best methods to manage waste. Included are process modifications to improve yields, selection of new, different raw materials to reduce toxicity, improvement of waste recovery systems and, in some cases, development markets for by-product materials or materials that were once considered waste.

Let me just highlight three examples of how this can work:

1. At our Corpus Christi plant we manufacture "Freon" which generates significant quantities of anhydrous hydrogen chloride as a by-product. As a matter of fact, at full production capacity, it generates about 350 million pounds per year of this by-product. The conventional method for handling this material would be to quench it with water and dispose

of it as a hydrochloric acid waste. Instead, for both economic and environmental reasons, the plant installed a $16 million conversion unit to produce chlorine from this by-product. The chlorine is reused in the "Freon" manufacturing operation—that's 315 million pounds per year of chlorine. Incidentally, the hydrogen which evolves is piped to the boilers and burned safely as fuel.

2. At our Edge Moor, Delaware, plant we manufacture titanium dioxide pigment. A by-product from this operation is a significant quantity of aqueous iron chloride. In the past, this material was barged to sea for disposal. As a result of R&D and engineering efforts, this material has been upgraded so that it can be used by water and wastewater treatment facilities as a coagulant. Marketing efforts have resulted in the sale of 65–75 thousand tons per year.
3. At our Victoria, Texas, plant, where we manufacture numerous intermediates for synthetic fibers, significant quantities of nonchlorinated hydrocarbons are generated as waste. Typically, these solvents had been burned in two incinerators on the plant. While this method did destroy the waste, and was environmentally sound, it was costly. Today, the incinerators have been dismantled and these solvents are being burned in our powerhouse to generate steam for the manufacturing process. Last year alone, the plant saved more than $10 million in fuel oil costs by burning these wastes as fuel.

It is interesting to note that while all of the examples I have cited result in waste reduction, different techniques are employed. There was better utilization of the primary raw material resulting in an improved yield of polyethylene, and less waste. Chlorine was generated from a by-product of the original Freon manufacturing operation. It is recycled back to the beginning of the process as a raw material. Both of these examples are considered reduction of wastes at the source and at the same time they can be termed recycling of materials.

In the ferric chloride example in the past, we had disposed of this material as a waste. We have converted it to a co-product: In the Victoria example we have also taken material, which was being disposed of as a waste and directed it to a beneficial purpose—a fuel source. While these cases do not return material to the primary process, they still meet our stockholder and societal obligations. We are no longer discarding a resource.

In addition to accepting the challenge associated with waste reduction at the source, Du Pont believes government should share in the effort by designing regulations so that they encourage sound environmental practices to minimize waste generation. I would like to highlight two areas where this is not the case.

First—the definition of solid waste in the regulations is such that many facilities recycling hazardous materials would be required to obtain RCRA permits. One result will be significant increases in costs due largely to the administrative workload for no improvement in our ability to protect the environment. Another result will be the public perception that this beneficial recycling constitutes disposal of waste, when just the opposite is true.

Second—flammable solvents, which are by-products of a process, are classified as a hazardous waste. Due to this classification, the freight cost for such materials is significantly higher than it is on the incoming solvent—which, in many cases, has essentially the same hazard. The original producer must also have a RCRA permit before he can receive and purify these materials for reuse. This inhibits recycle or reuse of solvents by adding an unnecessary administrative burden.

Although the intent of the regulations is good, I question whether they in fact promote implementation of a national policy to minimize waste generation. *If we truly seek to encourage implementation of programs designed to reduce generation of waste*, we should make it more attractive to conduct *recycle or reuse activities which benefit the environment and the economy*.

Industry's responsibility with respect to waste reduction is multifaceted. We have a responsibility to continue to improve our processes and operations so that waste reduction results in improved earnings for our stockholders. More importantly, we have a responsibility to the society in which we operate to protect the environment while continuing to improve the American standard of living. If American industry is to discharge these responsibilities, the challenge is to create an organizational commitment to this effort and a working culture which fosters sensitivity and knowledge of the issue at all levels in the organization. I believe this challenge has been accepted within Du Pont and within American industry. As a result, we will see considerable reductions in the percentage of waste generated per pound of product produced, just as we have seen reductions in the consumption of energy over the last 10 years. In order to improve upon this effort, we must continually modify the way we operate. Perhaps Peter Drucker, the business consultant, put it best when he said . . . "the only means of conservation— is innovation."

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 48–50, March 1986

Biological Diversity and Development: A Legal Perspective

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Chairperson, Wildlife Program, Environmental Defense Fund

The goal of economic development, whether within an industrialized nation like the United States or the mostly rural nations of the Third World, has often been perceived to be at odds with that of environmental protection. That perception, which causes trouble enough here, where the common aspiration is to make a very good standard of living even better, presents an immense challenge elsewhere, where many aspire only to improve upon a bare subsistence standard of living. That challenge is even more difficult when the environmental resources at stake are not clean water needed for human consumption or productive soils for crops, but rather living wild species offering no immediate, discernible benefit to human welfare.

Despite this troubling perception, the scientists on this panel and elsewhere assure us that, in fact, the advancement of human welfare and the protection of biological diversity are intimately bound together. Indeed, the prospects for long-term, sustainable development depend in part on our ability to refrain from unraveling the intricate web of life in which we ourselves are placed. This is because living wild resources are the reservoir from which we will need to draw many of our future discoveries in medicine, agriculture, and industry. It is also because collectively they perform a myriad of ecological services, from storm water retention and pollutant consumption to photosynthesis itself, that are essential for our well being.

If we assume the scientists are right, two clear imperatives emerge. One is to enact laws and design and implement programs for the conservation of biological diversity. There are several such laws and programs in the United States. Perhaps the best known of them is the federal endangered species program spawned by the Endangered Species Act of 1973.

The Endangered Species Act has often been described—both in the United States and elsewhere—as model legislation for the rest of the world. Its stated goal, quite simply, is to prevent the avoidable extinction of wild plants and animals. The means it uses to attain this goal include prohibitions on hunting and trade, the acquisition and protection of important habitat, and a rather novel command to federal government agencies that none of their actions jeopardize the survival of any threatened or endangered species. These are the familiar tools with which legislators have long attacked wildlife conservation problems—prohibitions, commands, and public expenditures for land acquisitions.

How well have these familiar tools fared in the effort to prevent the extinction of species? There are, most assuredly, some signal successes. Two that you may see near here are the American alligator and the brown pelican. Restrictions on hunting have enabled the former to recover, while the latter, along with the bald eagle, and peregrine falcon, owes its recent resurgence to the elimination of DDT and other persistent pesticides. These examples illustrate the very important point that the road to extinction can be reversed and that this can be done without significantly retarding or affecting economic growth.

At the same time, however, the limits of what can be achieved through such conservation programs are becoming increasingly apparent. Today, nearly 400 species of plants and animals in the United States enjoy the protection of the Endangered Species Act. Yet more than twice the number have been identified as needing the Act's protection, but still await the slow process of adding them to the protected lists. Many of these have declined dramatically while awaiting the Act's protection; some have disappeared altogether. Even for species that have long benefitted from the Act's protection, survival has not been guaranteed. Three of the best known of these, three species that have been protected since the very inception of the endangered species program, are closer now the brink of extinction than ever before. The California condor, of which perhaps three dozen birds still survived in the late 1970's is now down to only five or six birds in the wild. The black footed ferret had one known population with nearly 130 animals in it in 1984; now perhaps no more than three animals survive in the wild. Finally, right here at Disney World, the last two specimens of the dusky seaside sparrow—both males—await the certain end of their species. Add to these specific examples the general problem of inadequate funds for habitat acquisition and other recovery efforts, and one can better understand why the model conservation legislation we so often tout here is unlikely to stem the torrent of species losses now occurring in much of the rest of the world.

If conservation laws and conservation programs, by themselves, are not sufficient to serve the goal of preserving biological diversity, what then is the second imperative in order to heed the scientists' warning that development, to be sustained, must ensure the protection of biological diversity. The answer, I think, is that the full force of our intellectual efforts must be given over, not to decrying the adverse environmental effects of development, but to promoting development in ways that reduce both social and environmental costs. To assure you that this is more than just an abstraction, let me offer one current, concrete example from within my own organization.

Southern California, as most of you know, has the unusual characteristics of being very dry and very populous. The region's potential for growth depends upon the availability of water. Historically, to supply water to the burgeoning populations of Los Angeles and other metropolitan areas, the region looked east to the Colorado River and north to the scenic rivers of northern California. Dams and diversions drastically altered the environments and the diversity of many of these rivers. Today, growth and the thirst for still more new sources of water continue.

At the same time, between Los Angeles and San Francisco, a new problem has come to be recognized within the last few years. Through irrigation, the normally arid San Joaquin River Valley has become one of the most productive agricultural regions in the country. But because of the area's geology, irrigation water becomes trapped near the surface unless drained by subsurface tiles. These tiles carry the drained water through conduits that eventually empty into the large evaporating ponds that comprise the Kesterson National Wildlife Refuge. About two years ago, people began to notice serious abnormalities and high mortality among the waterfowl using the Refuge. The cause, it was determined, was selenium, a trace element being leached from the soils of the San Joaquin River Valley by irrigation water.

The impulse that has perhaps become too common in the environmental movement was to recommend the drastic step of cutting off irrigation water to the valley—drastic, because it would put an end to agriculture itself in the region. Some environmentalists recommended exactly that. But we at the Environmental Defense Fund searched for a positive alternative that might solve the problems of both the waterfowl at Kesterson and the fisheries and other wildlife of the northern California rivers being eyed for future dams.

What we have recommended is that the irrigation wastewater be collected and treated in reverse osmosis desalting plants, and the resulting brine placed in solar ponds for electricity production. The technologies for both of these processes are recent and tested, though on a smaller scale than envisioned here. The products of these processes are clean water and electricity and a concentrated waste that can be more easily and safely disposed of. Because the irrigators are the beneficiaries of the long-term, low-cost federal water supply contracts, they could, at a substantial profit, sell the reclaimed water to Los Angeles for less than the city would have to pay for the same amount of water from new dams. One of the jobs for our lawyers has been to persuade the federal government that water it supplies to irrigators can lawfully be resold in this way. Assuming those institutional hurdles can be cleared, the net result is that Los Angeles can meet its immediate water supply needs without building more dams, productive irrigated agriculture can continue in the San Joaquin River Valley, and the waterfowl of the valley cease to be threatened by the hazard of selenium. In short, the goals of development and protection of wildlife and the environment can both be served.

The challenge facing all of us concerned about biological diversity and development is to multiply examples like this both in the United States and in the rest of the world. Often, as in the example cited, novel technologies will be needed and, equally often, the legal challenge of adapting institutions to faciliate those novel technologies will be essential. In this way, we can perhaps begin to change the perception that the goals of economic development and environmental protection are at odds. By changing that perception, the objective of preserving biological diversity embodied in our conservation laws and programs will gain important allies.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 51–55, March 1986

Zoological Parks and Aquariums—Bridges of Learning

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Vice President, Zoological Director, Sea World, Inc.

Charles Lindbergh said "the Human Future depends on our ability to combine the knowledge of science with the wisdom of wildness" . . . nature. Wise words. It is evident from this gathering of respected leaders from state and Federal government, industry, academia and the environmental community, that we acknowledge and agree with the wisdom of this statement.

The richness and diversity of our natural resources promote a multitude of uses that are deserving of responsible stewardship. Technology has made many important advances and improvements for mankind through the manipulation of the physical and biological elements of our biosphere. And yet, new technology has brought with it some problems, i.e., atomic energy/nuclear war, pharmaceuticals/illegal drugs, chemicals/toxic wastes, space exploration/tragic accidents, and fears that genetic engineering will bring us Aldous Huxley's "brave new world." But the benefits of technology overcompensate for the negatives. And because progress is an on-going process, we must continue to monitor existing programs, increase our research capabilities, and where necessary, make programmatic readjustments. We must prove that technology is not poison.

From experience, we at Sea World know that constructive progress can best be made in an atmosphere of mutual concern and cooperation. The Charles A. Lindbergh Symposium "Technology and Environment: The Search for Balance," is a timely and important dialog on this important subject. It is my hope that this and other forums of its kind will be successful in promoting a thoughtful, cooperative and constructive discussion of the important promises that science and technology hold for the world in 1986 and beyond. Let us interrelate our areas of expertise and work with one another . . . collectively, to develop safe, new technologies. We must never give up our hopes of understanding and improving our world . . . in striking a balance.

Zoological parks and aquariums in the U.S. have an abiding interest in the implementation of Charles Lindbergh's philosophy. We approach this from a standpoint of providing to the public education, recreation and cultural enjoyment through the scientific study and conservation of wildlife. In this way we endeavor to promote a greater awareness, understanding, and appreciation of wildlife and their environment. We do this with the hope of contributing to a more informed and responsive citizenship in tomorrow's technological society. At the same time our roles in biological research, and our very significant commitment to the provision of sanctuary for endangered and threatened wildlife, are undisputably important.

That, you think, seems a bit overwhelming? Sometimes we think so as well. What, then, keeps all this in focus? *Learning*. The goal of every institution is to become a bridge between its visitor, staff, and the natural environment. We cross that bridge as "learners." From the first-time visitor to the long-time research director, there are functions at work within these institutions that motivate learning. These functions are research, education, and recreation. Obviously, each function must be approached within differing perspectives. But because the goal is learning, there is no conflict in these differing perspectives.

Today I wish to share with you the integral roles these functions have played in advancing "the knowledge of science with the wisdom of nature."

Research Function

The problems of conserving threatened species are enormous. The U.S. Endangered Species Act lists a conservative 828 species, 331 of which are found in the U.S. But the Convention on International Trade in Endangered Species, the International Union for the Conservation of Nature and Natural Resources, and other international organizations list even more.

U.S. zoological institutions are making important contributions to international conservation through captive breeding programs, scientific research, and other types of conservation efforts. These efforts call for coordination and cooperation among all institutions concerned with a particular captive species. Increasingly, the community will work together, as consortiums, to fund large and expensive field projects, as well. Captive propagation programs make contributions to international conservation objectives by 1) provision of alternative refuge for species facing extinction due to loss of habitat, 2) provision of animals where and when appropriate for repopulation of natural habitat, and 3) when the odds no longer favor survival, to delay extinction through captive propagation for the purpose of conservation/education programs, i.e., as living monuments to a species extinct in its free state.

In addition to the intrinsic reasons for our efforts, species should be saved from extinction in order to maintain ecosystem stability. And, of course, the disappearance of any species is a tragic loss of scientific information with potential application to future human needs.

Species helped by zoological breeding projects include the Pere David deer, Przewalskii's horse, the European bison, Nene goose, snow leopard, Humboldt's penguin, trumpeter swan, black rhino, hippopotamus, tapir, okapi, addax, golden lion tamarin, and Bali mynah. The list grows as more and more institutions become successful in preserving the genetic integrity of other species in jeopardy. Conservation programs conducted in captive environments require a conserted effort and expense, and they require time.

In order to be viable for long-term captive propagation programs an adequate number of genetically-diverse animals must be available for reproductive management. Because inbreeding is always a potential problem, the species must be reproductively manipulated on a total captive basis. Breeding must be by computation rather than by chance. Breeding by whim leaves the species susceptible to complications resulting from a lack of genetic diversity, and adaptability over the long run is jeopardized.

While standard breeding procedures are still practiced by most institutions, we recognize that high-tech means of improving reproductive potential will produce important benefits for some long-term endangered species propagation programs. The genetic mangement programs so well demonstrated in domestic livestock are still in their infancy for exotic wildlife. The reason is that captive husbandry must first be established, followed by basic reproductive and behavioral research. These programs can only be accomplished when we understand in biological terms the animals we are trying to preserve. That includes a knowledge of genetics, reproduction, immunology, pathology, clinical medicine, physiology, metabolism, energetics, nutritional requirements, etc. When these basics are well-understood, we can move and are moving into the consideration and application of advanced reproductive technology, including artificial breeding, gamete storage, sexing, and transplantation. We are confident that the future for many rare and endangered species will be enhanced through advancing reproductive and other bio-technologies. We point to the following partial list of successes:

Artificial Insemination: Giant panda, gorilla, Speke's gazelle, Persian leopard, guanaco, Sarus crane, and many others.

Embryo Transfer: Bongo/eland; guar/domestic cow; Bengal tiger/African lion; quarterhorse/zebra; and homologous transfers with baboons, rhesus monkeys, water buffalos, and elands.

In Vitro Fertilization: Primates (baboon).

Cytogenetics: Many look forward to the day when frozen embryos can be successfully thawed. When this is accomplished we can begin to consider gamete retrieval from wild free-ranging animals for the purpose of improving the genetic base of those in captive environments (and vice versa).

Educational Function

We note with dismay that science education is deteriorating as an educational base. Students are taking fewer courses in science, and fewer courses are being offered. And regrettably, we are experiencing a serious shortage of qualified teachers. Of course, declines in student achievement are being documented. Zoological parks and aquariums, as providers of quality educational resources, are responsive to the widespread concerns over educational quality. We believe that the learning process should build personal "data bases" through a continuum of experiences found in the school curriculum, and augmented by a community's scientific resources. As partners in the educational enterprise, we are important resources for scientific learning. We are seeking to fulfill our educational responsibilities in the area of scientific literacy through the integration of our resources within the curriculum and other programs designed for American students at all educational levels.

Zoological parks and aquariums act as living classrooms for some 20 million school children every year. In these "classrooms" students are instructed through a "hands-on" approach.

The educational programs at Sea World are truly representative of the very best that the zoological community provides. As an example of, in our case, the "get wet" approach to education practiced at Sea World, consider the following:

> Since the development in 1972 of "Exploration Breach", Sea World's formalized educational program for elementary through collegiate levels, over 2.5 million students have had the opportunity to directly experience and learn about marine life at one of the three Sea World parks as part of their curriculum. Other programs include: "Underwater Friends" for grades K–3; Youth Awards, for Campfire, Scouts, and other youth groups; Career explorations; "Interworlds" for students K–4; and in-depth studies for high school and college students (many in cooperation with the University of California, San Diego; San Diego State University, and the University of Florida system.) Sea World also provides continuing education units which bring marine science instructors

to the classroom, and a preceptorship program for upper level veterinary medical students interested in zoological medicine.

In recent years, several very popular special programs have been developed. Gifted students' programs are presented for qualified students in grades K–6. Three special education programs are offered for mentally-challenged, visually-impaired and severely disabled students. Each is a multi-sensory program designed for students who benefit from the individual approach. Sea World's Education Department also offers free curriculum aids and teacher orientation programs.

In addition to the organized education programs, trained interpreters/narrators are stationed at all major animal exhibits to answer visitors' questions and present educational information. Other educational materials are presented in our award-winning graphics displays located in exhibit areas.

Recreational Function

As our society become more urbanized and crowded, zoological parks and aquariums will provide the only available exposure to the world of nature for increasingly large numbers of people. Currently, these institutions accommodate annually over 110 million out of a nationwide population of 239 million. We realize that there are recreational activities that offer the public encounters with wildlife in natural settings, i.e., safaris, oceanic cruises, outings in natural parks, etc. Our programs are not designed as substitutes for these experiences, but rather as a complement to them. However, unlike most wilderness experiences, where wildlife is only partially visible or otherwise inaccessible, our programs afford the public with opportunities to personally experience the beauty, intelligence, and agility of these wildlife forms. This exposure is especially significant to those visitors who have limited opportunities to experience such wildlife in natural settings—those living in large cities, the impaired, the young, the elderly, and the impoverished. Experiencing wildlife only through one-dimensional photographs cannot replace the sensation one feels as the curious trunk of an elephant grips your fingers, or at the touch of a satiny-smooth dolphin, glistening before you. Such experiences form lasting bonds of affection . . . and they're great fun!

Whether directly, through the proceeds of an admission charge, or through other means such as taxes, the recreational function is the means through which our educational and research functions are financed. It is a function that is important.

Conclusion

The purposes for which we exist and serve are necessary. Our purpose is reflected through our focus on research, education and recreation. Through our research projects, we have made important advances in captive husbandry and propagation programs, while contributing information vital to basic and applied wildlife science. In addition, we cooperate with local, state, federal and international governments, and the academic community, and have a long and impressive record in the recovery and rehabilitation of diseased and injured wildlife. Hopefully, these advances will continually increase our ability to generate information for the detection and management of environmentally-related changes to natural ecosystems, offering better and more widespread protection of our wild fauna.

In the spirit of combining scholarship with showmanship, we combine educational and recreational programs. This is done with a strong sense of responsibility for conveying ecologically-sound and important information to the public. In this way, we endeavor to promote greater awareness, understanding and concern for wildlife and their natural environment, with the hope of contributing to a more informed public, and thus building a more responsible society.

Charles Lindbergh knew that nature is like a "canary in a coal mine." That its decline signals our own. He was, and we are, concerned. We believe he would have recognized the roles we play in the conservation of nature and in our contributions to scientific knowledge. And we also believe that he would have endorsed such sites for public education and recreation, where wildlife can be maintained in settings that give them a good chance for long-term survival. As bridges of learning between man and nature, we honor the spirit and philosophy of Charles Lindbergh.

I've enjoyed this opportunity to speak to you, and I hope you will take some time to visit Sea World while you are in Orlando, and observe how the discoveries of science and the products of technology are preserving and improving the quality of life. Thank you.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 55–60, March 1986

The Role of Sustainable Wildlife Use in Conservation and Development in the Tropics

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Upon reading the theme for this symposium, "Technology and Environment: The Search for Balance", I thought I might appropriately entitle my talk, "Technology and Wildlife: The Search for Sustainable Use", for the problems and solutions to the sustainable use of wildlife exemplify that search for balance between development and biological diversity.

What do we mean by the term "sustainable use of wildlife resources"? By sustainable we mean that the use made of a wildlife population is at such a level that the use can be maintained indefinitely; that is, the use does not exceed or destroy the population's ability to reproduce and replace itself. Use can mean a broad array of things, from the hunting or trapping of animals for food, fur or sport, to bird watching. Wildlife, in the broadest sense of the term, can mean any wild animal or plant, terrestrial or aquatic.

Sustainable wildlife use stands at the crossroads of wildlands conservation and human technology and development. In simple terms, we can think of the sustainable use management of wildlife as human society knowledgeably manipulating wildlife to produce, indefinitely, any number of goods and services benefiting human development.

I would like to focus on wildlife use in the tropics, where the biggest challenges are today and where it will have the biggest impact on both development and biological diversity. I will specifically talk about Latin America where I work.

There are three points I wish to make today concerning wildlife use:

1. The actual and potential contribution of wildlife to human development in the American tropics is underestimated by national and international agencies concerned with human development, and, because of this, development is bound to fail in many areas because sustainable wildlife use is not incorporated into the development plan.
2. The development of wildlife management in the American tropics will require innovative techniques and new concepts in natural resource management, for which the North American experience can provide only limited models.
3. Wisely implemented sustainable use programs of wildlife will be critical in meeting the challenge of conserving the vast biological diversity of the tropics.

The importance of wildlife in meeting basic human needs is, of course, most obvious in the case of indigenous peoples. Native Indians of the American tropics depend on fishing and hunting to meet their protein requirements, and on a variety of plant products for food, shelter and medicinal needs. Native peoples are, indeed, experts at extracting from a cornucopia of plants and animals all of their basic necessities and commodities. Unfortunately, most of this native knowledge about tropical wildlife management has remained within the domain of indigenous groups and a few anthropologists. Native expertise has been largely ignored by government agencies in charge of natural resource management and land use planning, most probably because it is incorrectly seen as unsophisticated, unapplicable to current societal needs, and producing little of economic importance for the country.

Colonists that have settled in tropical forest regions have also become dependent on local forest resources. In rural Amazonian Peru, more than 85% of the animal protein consumed by colonist villages is wild, of which more than two thirds is from fish (Pierret and Dourojeanni, 1967; Rios et al., 1973). This dependence by colonists as well as indigenous people on wild sources of protein is a pattern found throughout Amazonia, both in rural communities and in cities, and to a lesser extent in rural Central America. Nevertheless, technology transfer from indigenous peoples to colonist populations in the Amazon must be enhanced to enable the diversified and sustainable use of forest and river resources practiced by many indigenous groups to be more broadly tested and applied.

Some species also have tremendous potential for providing expendable income for rural inhabitants and for contributing to a country's trade balance. One species currently under research is a large lizard of the genus Tupinambis which is found throughout much of South America, but is particularly abundant in northern Argentina where it is hunted for its valuable skin and meat. Argentine export figures show that an average of 1–1.5 million Tupinambis skins leave the country every year, with a total export value of 10–15 million dollars (G. Hemley, personal communication). Yet, only within the last 2 years has any concerted effort been made to understand the basic biology and economic importance of this species. Preliminary calculations indicate that protecting the chaco forest for Tupinambis management may produce much greater economic returns for local inhabitants than conversion of the forest for cattle (D. Werner, en lit.).

One might ask if any mangement is necessary. Can't these species hold their own? Experience answers that heavily harvested species cannot sustain themselves without management. In fact, many Amazonian species of potentially great importance for economic and/or subsistence uses have been driven close to extinction by overharvesting within the last 50 years. Among the most important, for example, are the American and Orinoco crocodiles. The high value of their skins stimulated intensive harvesting that has left the Orinoco crocodile numbering in the hundreds in the llanos of Venezuela, and the American crocodile endangered throughout its range. With populations of these two species decimated, the caiman crocodile, with less valuable skin, is now being heavily exploited. An estimated 1–1.2 million skins are taken annually from the pantanal region of Brazil, Paraguay and Bolivia. The export value exceeds 15 million dollars, and the total value of these skins, once tanned, exceeds 100 million dollars (G. Hemley, personal communication). If properly managed, even these harvest levels may be sustainable, but we lack sufficient information to know.

Primates provide another example of the consequences of ignoring management needs. Work by myself and Peruvian colleagues demonstrated that in forest areas of Amazonian Peru and Bolivia outside parks and reserves, numbers of the large species of primates, such as spider monkeys and howler monkey, had been reduced to virtually zero over extensive areas because of hunting pressure (Freese et al., 1982). Large primates, because of their low reproductive rate (one offspring every 1 or 2 years), are not adapted to withstand high harvest rates. Primates could better withstand low harvest rates required to supply the needs of biomedical research, and local inhabitants could reap higher profits since many species are worth $100–300/individual. The Primate Project in Iquitos, Peru has begun such a management program.

Examples abound concerning the uses and importance of native plants. The Brazil nut is a product of South American forests that is familiar to all of you. It is not, however, grown in plantations like most other nuts you eat, but rather must be harvested from natural forests, a point I will return to later. Brazil alone exported over 43,000 tons in 1979, and unknown quantities of this protein-rich nut are consumed locally (Balick, 1985). The U.S. imported 16 million dollars worth of Brazil nuts in 1976 (U.S.D.A., 1978).

On a broader scale, in 1979 the value of 31 species of native plant products harvested in Brazil was $137,000,000 (Balick, 1979). Considerable publicity has recently been given to the actual and potential pharmaceutical products extracted from tropical forest plants. It is estimated, for example, that 8,000 plant species from the American tropics have anti-cancer properties (Duke, 1982).

The science and technology for managing these diverse plant and animal resources are embryonic in Latin America. Many of the basic principles of wildlife management developed in North America can be adapted to tropical habitats, but several factors will require the development of new approaches. The life of the wildlife manager in the tropics is complicated by the shear diversity of plants and animals, and the complexity of interactions that must be considered. In a few square miles of deciduous forest in the eastern U.S., the manager may have to deal with only a few dozen species of trees, mammals and birds, but in Amazonia he or she must deal with hundreds of species of each in the same area, many of which have not yet even been described by science, let alone studied in detail. Interactions between organisms may follow completely different patterns in temperate and tropical habitats. For example, the flowers of temperate forest trees tend to be wind pollinated, whereas tropical trees generally depend on animals (bees, bats, birds) to carry pollen from one flower to another (Prance, 1985).

This basic difference could greatly influence the management of trees or wildlife species in the tropics. The Brazil nut tree provides a lucid example, for it is pollinated by only certain large nectar gathering bees (Prance, 1985), which apparently must have other sources of nectar when the Brazil nut tree is not in flower. Thus, Brazil nut trees have not been successfully cultivated in large plantations, but rather are best maintained in mixed or natural forests so that the pollinator bee populations are maintained (Balick, 1985).

The development of management programs for Amazonian fishes provides another striking example of how management of wildlife in tropical ecosystems may require major adjustments in our thinking. As with terrestrial wildlife, the tropical waters of Amazonia carry many more species than temperate waters. The Amazon and its tributaries contain probably 2,500–3,000 species of fish, with roughly only half known to science (Goulding, 1980). Based on our knowledge of Amazonian fishes just a few years ago, we might have thought that the major question concerning their management would revolve around the levels of harvest that their reproductive rates could support. But recent work on Amazonian fishes by Goulding (1985) in Brazil has revealed another few facet about the complex connections within tropical systems that we must address in managing Amazonian fisheries. He has documented that of those fish that are most important for human consumption, roughly 75% feed on fruits and seeds that drop into the water in floodplain forests.

Thus the sustainability of the most important source of protein for Amazonian people—fish—depends primarily on the conservation of the floodplain forests that line the Amazon and its tributaries. This is the kind of direct link between forest conservation and human sustenance that fulfills the wildest of conservationists' dreams about arguments for saving tropical forests. The case, however, is not so cut and dry, for these floodplains, because of the annual deposition of sediments from the rivers, contain some of Amazonia's richest agricultural soils and thus their forests are heavily cut to make room for rice and other crops. Clearly, a balance must be reached between these conflicting land uses, and much more research is needed to design the best management options.

Besides the biological novelties and questions to be worked out, new concepts must be developed integrating human settlements with the management and use of wildland resources. Among the tremendous challenges to be faced is how to manage human use of wildlife resources on extensive public lands where equal access by all with minimal control can undermine attempts at resource management. Another major challenge is to ensure that local people understand and benefit from wildlife management programs.

This integration of local human populations with wildlife and wildland management is being explored with some innovative approaches in Latin America that could affect large areas of tropical forests in the short term and serve as models for extensive land use policies in the long term. An example is the Pacaya-Samiria National Reserve in Northern Amazonia Peru. This reserve covers some 20,000 sq km of lowland tropical forest, meanderous rivers and owbow lakes. Thousands of people live along the two rivers that border the reserve, many of whom depend on the reserve for fishing and hunting, for both subsistence and commercial purposes. One of the most popular resources of the reserve is the giant primitive fish, *Arapamia gigas,* which reaches lengths of more than 2 m and may weigh over 125 kg (Goulding, 1980). Increasing demand from markets as far away as Lima, however, is placing heavier pressure on the reserve's resources. The Peruvian government has designated the area as a national reserve with the objectives including the wise use of its fish and wildlife resources *and* conservation of its natural systems. This is the largest such sustainable use management area in Latin America. Peru is now preparing a management plan with strong input from local inhabitants which will ensure that they continue to have access to the reserve on a controlled basis to meet their own subsistence needs, but which will more tightly control large-scale, commercial fishing and hunting.

Another example is Mexico's Sian Ka'an Biosphere Reserve on the east coast of the Yucatan Peninsula. This 5,280-sq-km reserve encompasses a broad diversity of habitats including tropical forest, mangroves, large bays and estuaries, extensive beaches and a barrier reef, with Mayan archeological ruins scattered throughout. In Sian Ka'an, the objective is to integrate the conservation of these habitats with small-scale human development programs. One such program involves working with a small community of well-organized fishermen who live in the reserve. These fishermen harvest 40–60 tons of spiny lobster tails annually from the reserve and earn a very healthy income in the process. However, this relatively new fisheries, until recently, was developing with very little information on the lobster's population or biology. A plan is now being prepared to better manage and monitor this fisheries to ensure that it continues to be a valuable economic resource for the region. Meanwhile, reserve managers are looking at forest resources in the reserve, such as orchids, that might be harvested sustainably without deleterious effects on the reserve's ecosystem.

The wildlife and wildland management programs just described are part of a clear message coming out of many tropical regions of the world, a message of importance to both those primarily interested in human development and others in the conservation of biological diversity. For development-oriented sectors, the message is that in many tropical regions, especially in tropical forests, development must look towards making use of native plant and animal resources in natural or semi-natural ecosystems because conventional systems of agriculture do not work, and because local people are predisposed to living off native resources. It must be realized, however, that for many tropical forest systems and species, utilization cannot be intensive, but rather must be practiced over relatively extensive areas if resources are not to be over-exploited.

The significance of this message for biological diversity is, in the simplest terms, use it or lose it. This is not to say that strictly protected areas such as national parks do not have a major role in the conservation of wildlife and habitats in the tropics; they do, and indeed national parks and equivalent reserves will continue to be the primary method for protecting areas of exceptional uniqueness and diversity. However, such protected areas can never cover more than 5–10% of a country's territory, and we know that much more extensive areas must remain in natural or semi-natural condition in the world's tropical forests if we hope to conserve the vast array of organisms found there. The question therefore becomes: How do we manage those 90–95% of tropical forest lands outside protected areas? If sustainable use of wildlife resources on these lands cannot be demonstrated, there will be intense pressure to open them up to uses such as logging or slash-and-burn agriculture that are less sustainable and more destructive of the natural systems.

In the past, support for research and development of sustainable use of wildlife resources in the tropics has fallen between the cracks. Development agencies viewed it as too unconventional, underestimated its importance, or simply looked at it as wildlife preservation guised as development. Conservation agencies saw it as too use-oriented or failed to see its overall role in wildland conservation. That situation, happily, is changing, as the crack between development and conservation agencies is narrowing and we see that sustainable wildlife use in the tropics provides a common ground for our objectives of sustainable development and the conservation of biological diversity.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 60–62, March 1986

The Grand Array of Life on Earth

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We hope in this third section, to give a biological perspective, namely how life on earth, and *our* life on earth should relate one unto the other.

First, we should consider life itself, this exceptional development which appears to be confined to our planet alone. Life is a high energy operation, because it takes great amounts of energy to build complex structures—more complex than anything that occurs in the vast segment of our solar system and universe which is non-living. It takes energy, too, to maintain these complex structures against the general tendency of the universe away from structure and toward chaos—so elegantly summed up by Josiah Willard Gibbs as the Second Law of Thermodynamics, but certainly more widely and unwittingly in human cognizance in the lines about Ozymandias, King of Kings.

The necessary energy comes largely from the sun and is converted by green plants into forms usable by them and other forms of life—a miracle that we unconsciously celebrate thrice daily as we go to table, or eschewing ceremony, at least acknowledge by grabbing for a caloric ring, as the merry go round of our lives rushes past a fast food establishment. The order and structure of human achievement, whether libraries, machines, governments or edifices are but extensions of the ability of life to produce order and structure.

But living things are not immortal, they must inexorably succumb to Gibbs' Second Law, yet can manage to escape by the device of reproduction. Life is very much in the business of making more of itself, which is why sex keeps rearing its head. Without meaning to descend to schoolboy snickers and titters, it *is* biologically meaningful that sex is pleasurable—were it not, it is inevitable that the particular species would become extinct. It is reasonable to suppose that reproduction is pleasureable for each form of life on earth. One cannot help but wonder what it must be like for species like the Century Plant for which it only happens once in a lifetime. I dwell on this point not to titillate like a saucy dime store novel, but because this universal feature of life on earth, is also a source of great hope for those of us concerned with maintaining the variety of life on earth. Given a chance, each species will perpetuate itself, but from extinction there is no return, no escape.

We know that life on earth comes in great variety, but science, cannot as yet, say with any precision how diverse life on this planet actually is. When I first became interested in natural history some thirty years ago, the general estimate was on the order of a couple million species. Later estimates of five and ten million began to be heard and just recently based on discoveries about insect life in the rain forest canopy, the estimates have risen to about 30 million (Erwin, pp. 59–75 *in* Tropical Rain Forest: Ecology and Management, S. L. Sutton, T. C. Whitmore, A. C. Chadwick, eds., Blackwell Scientific Pubs., Oxford, 1983). This means that we know the weight of the moon, and perhaps even the strength of the magnetic fields of Uranus, to a greater precision than we have taken the measure of the variety of life—really a most fundamental datum of science, and one of very central interest to ourselves as part of it all (Wilson, Issues in Science and Technology 2:20–29, 1985). This is a very disturbing state of ignorance especially when we are on the verge of losing a major fraction of the variety of life on earth. The impending loss is in large part due to unpremeditated or unwilling actions by an ever larger human population, acting in a variety of environmental destructive ways, prominent among them the destruction of tropical forests which harbor about half of this astounding variety.

The tendency to diversify is a fundamental theme echoed throughout the history of life on earth, checked and occasionally reversed only by traumatic events, such as the meteor induced dust cloud currently believed to have triggered the demise of the dinosaurs (Alvarez et al., Science 208:1095–1108, 1980; Wilford, The Riddle of the Dinosaur, Knopf Div. of Random House, New York, 1985). We have only the most rudimentary notions as to why there is such a universal tendency. It is all too easy to accept it as a fact without understanding, even to say that it really means we needn't concern ourselves with the loss of a species here or there, for after all, with certainty more will eventually arise. Yet such an uncaring attitude ignores that the time scale for replenishment of diversity impoverished by human action, is on a greater scale than a human life span, and will do little good for those of us here now, or even the next generations. Nor does it recognize that each and every species is a reflection of a long evolutionary history, stretching back to the origins of life on earth. Each also reflects recent environmental history and problems, which the extant organisms, by their very survival, have demonstrably dealt with and developed solutions for. These are solutions often of immediate relevance to practical human affairs, whether it be resistance to viral diseases of corn discovered in a wild perennial corn species in the mountains of Jalisco, or the ability to remove mercury or isocyanate from aquatic environments demonstrated for two yeasts in eastern Pennsylvania streams (R. Patrick, pers. comm.).

The tendency to variety also expresses itself on a local level in those biological aggregations of interacting species science calls ecosystems. Almost all natural ecosystems contain large numbers of species, many of which are rare, and the functions of which in the system are either unknown or *apparently* negligible. Yet why do almost all ecosystems have such variety—variety incidentally that is badly diminished in the face of toxic wastes and pollution? A "clean" environment is biologically diverse. A polluted or stressed environment is not, but rather is dominated by dandelions, cockroaches, or equivalent weeds and pests. I, and some others suspect the presence of the variety of species in an ecosystem is, by accident of history or otherwise, a measure of the flexibility of that system in time of change: when mercury contamination lowers the diversity of a stream community the particular yeast species becomes abundant and the ecosystem persists while the yeast busily cleans it up.

Certainly we know enough to say that maintaining biological diversity is almost entirely a matter of plusses for human society. Dependent upon it is the ability of ecosystems to continue to function in ways on which we in turn depend. The life sciences, are surely (without in any sense belittling other fields of inquiry) the most important branch of knowledge for ourselves as living organisms. Understanding them depends squarely on maintaining the basic body of data about life on earth and this is best summed up and measured by the diversity of life on earth. And each and every species holds the promise for discrete highly practical contributions to human welfare—an enzyme or observation can transform the world.

These fundamental truths tend to be obscured by the triumphs and glitter of our technology. And it is hard not to be distracted. When I think of a year spent on Maryland's Eastern Shore as a boy, in a house with a woodstove and a telephone with no dial, it seems nothing short of miraculous to live in a world of microwaves, Concordes and satellite assisted direct international dialing to some of the most remote places on earth. Another fatal flaw will be to let this blind us to our true biological nature, to let us think for example that biological engineering means we can dispense with diversity because we can replace what we have lost—instead of the reality that biological engineering merely increases the value of the biological library that the diversity of life on earth represents. Indeed from another perspective it is very clear that humans are best served by landscapes that are both domestic and wild, and that humans dwelling in biologically impoverished landscapes tend to lead an impoverished existence. The best measure of our success in maintaining a balance between the world of technology and the world of our biological nature, will be the extent to which we protect biological diversity. The wisdom of wildness (to borrow Lindbergh's term) rests on valuing and protecting each and every species, and in protecting that grand array of realized possibilities of living systems that we term so simply: biological diversity.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 63–68, March 1986

Impact of Development on Arid Rangelands

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Biological diversity has been affected adversely by two major forces in recent times. The first is growth of the human population and the second is technological development. Surely the rest of the biological world must regard us as a species that has reached plague proportions demanding vast resources from the land. We have achieved a large part of the support of our enormous numbers through technological capacities to make rapid and large scale changes in the land, changes affecting all of the other organisms sharing the environment with us.

The effects of the large population size and technological development have been to reduce biological diversity and to diminish the capacity of land to support biological systems including those from which we draw our own support. These effects are particularly dramatic as we invade the lands which throughout history have been little altered by occupying cultures because of the difficulties in extracting from these lands resources to support human activities. The major land types greatly affected by current development are the wet tropics and the arid rangelands.

Under most schemes of development the wet tropics experience high rates of loss of the biological diversity that characterizes them. The loss can have catastrophic effects locally on soil structure, nutrient cycles and the interrelationships among many species integral to the stability and productivity of the life forms of these forests. On a large scale the loss is a threat to global climatic patterns and hence potentially effects all biological systems. The richness of the life forms destroyed through this process is not even fully appreciated by science.

In contrast, the arid lands, the other major land types affected by human population growth and development, are characterized by less biological diversity and greater environmental instability than are the tropics. The destruction of these dry lands, however, is no less rapid or dramatic than the destruction of the natural systems of the tropics nor are the long term effects of these losses likely to be of less consequence to the richness of all life dependent on these areas.

The form of development in the dry rangelands is mainly pastoral instead of wood products or crop farming for water is too limited to support growth of timber or allow cultivation of grain crops in most arid areas. The common result of pastoral development is loss of the stability of biological resources.

Dry rangelands have several characteristics in common. Many are in the 30 degree latitudes and are influenced by world wide climatic patterns. They experience low rainfall and high rates of potential evaporation. This water stress is often compounded by irregularity in the timing of rainfalls. These climatic factors present a series of physiological challenges to the perennial plants growing under conditions in which they must struggle to retain the water they have secured against a great evaporative force drawing it out from their leaves and roots. These plants must be able to make use of water entering their environment at any time while on rare ocasions they must survive having their roots flooded with an overabundance of water that takes some time to drain away or evaporate.

An example of this suite of characteristics drawn from the arid zone of South Australia comes from weather records at Brookfield Conservation Park. The average annual rainfall is 260 mm in the face of an average annual potential evaporation of nearly 2000 mm. The rainfall is distributed randomly among the months of the year and in the decade from the middle 1960's to the middle 1970's, registered rainfall fell below 100 mm in 1967 and above 500 mm in 1974. This low, erratic rainfall linked with high predictable rates of potential evaporation concentrated during the summers leads to great challenges to living organisms in hanging on to the water necessary to support life processes. The behavioral, physiological and evolutionary responses of native species are focused on coping with limited water and, in turn, inaccessibility of nutrients. The evolutionary resolution of the water challenges to the arid adapted biological systems of the dry lands is expressed in relatively few and highly specialized species of plants and animals occurring in sparse populations representing these species. The low biomass of organisms is in keeping with limited availability of water. A low biomass is all that can be supported.

Most arid lands have two plant systems. One is the ephemeral plants which are ubiquitous when growing conditions are good. These plants are short lived as visable green plants finishing with their major dependence on water within the brief span during which they have ready access to it. The rest of the time their presence in the system is inobvious as they wait out the dry times in the soil seed bank. As seeds, their metabolic needs for water are few and the threats to their existence relatively reduced. Pastoral profits ride on the ephemeral plants which spend as short a time as possible in making the seeds of their next generation of plants. Their short time spent as green plant seed factories offers only a short time that these plants are available as sources of nutrients and water to mammalian herbivores. Once they have set their seeds, their life cycle is generally complete and they vanish from the landscape even if they have not been grazed away.

The other plant system is that of the perennial plants including the lichens, shrubs, trees and species of long lived grasses. These are the physiological specialistsable to hold onto water while engaging in metabolic activity and retaining water against the large gradient of the potential evaporation. These persistent species are usually very slow growing and set seed only irregularly when favorable climatic conditions arise. They are vulnerable to overuse by grazing and browsing animals. Most of each plant's water and nutrient resources are required for its own persistence under conditions of environmental stress. Few are available for harvest by other species without serious effect on the individual plant providing them. An analogy can be made with a bank account gathering small percentages of annual interest. Small amounts can be withdrawn without loss of the principal. If large amounts are taken, all may be lost in time.

Native mammals in these rangelands generally occur in low numbers or are nomadic, following the availability of the ephemeral plants appearing with the rains. Thus in the natural scheme grazing pressure on perennial plants is light. Historically man's use of the dry areas was as a hunter and gatherer which did not have a major effect on the plant communities or as nomadic herders which mimiced the biology of the wild relatives of the domestic animals they depended upon. In these historical instances the dry rangelands were used as a renewable natural resource.

With increasing European pastoral development, these lands are used as a slow mining operation in terms of a gradual loss of biological productivity. Part of this effect is due to the introduction of cattle and sheep which have higher water requirements than do the native species endemic to the areas. The higher water requirements are coupled with food requirements needed to support reproduction, growth and a surplus of animals for sale. Just to meet the water requirements of domestic stock even during a relatively wet period, water is provided. The addition of this water then permits the animals to persist when it does not rain, at least for a while. In the absence of rain and in the absence of the ephemeral vegetation, the animals turn to subsistence on the perennial plants with the consequence of subjecting this vegetation to heavy browsing. In these two ways, providing artificially augmented surface water to stock and setting levels of herbivore populations through economic, not biological, forces, pastoral development extracts from the land support for greater numbers of herbivores than would be extracted in a system that was regulated by the availability of renewable resources produced by the intact ecological system. In other words, the system is regulated by human economic needs, development (wells, tanks, etc.), and by the ability of the land to support fodder plants.

Trends of development have also involved fencing or other means of reducing animal movements so that grazing pressure becomes constant throughout the year without times of rest for the vegetation. Stock confined to an area will eat the most palatable species first and turn to others sequentially as preferred plants disappear. Selective feeding at high stocking densities removes not only plant biomass but reduces species diversity over time as the palatable perennial species succumb to a greater harvest than their growth can support. The results of this slow mining operation have been loss of perennial species that are most palatable to stock. This is the equivalent of the loss of biological drought insurance on lands when relative drought occurs with most summer or dry seasons and whenever the rainfall fails. Loss of perennial plants destabilizes biological systems on these lands and transforms the land's productivity to a boom or bust economy.

Loss of the perennial plants has yet another consequence with far reaching effects. If the lichens, trees, shrubs and perennial grasses are lost, nothing remains to hold the fragile soil in place during a drought. Small rainfalls that come evaporate rapidly or follow land contours as they run off, escaping the holding capacity of structured soil and plant roots. Winds blow the dry, loose soil leaving behind the steps leading to the desertification of overgrazed pastures.

The boom or bust economy has a psychological manifestation, too. Boom times, years of good rainfall and a rich emerging ephemeral plant productivity come to be seen as "normal". Busts, dry years with a failure of the ephemeral vegetation are seen as "disaster", an unpredictable event that is out of place in the regular course of pastoralism in these areas. Setting the level of stock to that which can be supported without losses of animals during droughts and without loss of the perennial vegetation is to miss the profits of the good years. Few investors are drawn to this stable contract with the land. This basic pattern of pastoral development obtains in many parts of the world and is the underlying source of the crippling of the land and its dependents in Africa, North America, Australia and elsewhere in the world.

The arid zone of Australia has much in common with other rangelands but with some special features that simplify the consequences of pastoral development.

Australia was exploited suddenly just over a century ago rapidly transforming the natural system through an enormous invasion of exotic animals, cattle, sheep and rabbits. Australia has a streamlined system of generally low quality soils lacking in nitrogen and other nutrients and food limited herbivores with few predators to complicate the direct relationship between mammalian grazers and the plant growth on which they depend.

The system is run by rainfall and seasons, good ones and bad. Very small rainfalls may evaporate immediately or be too light to be of direct use to vascular plants. They may, however, activate the non-vascular plants, lichens and mosses. Certain of the lichens have the ability to fix atmospheric nitrogen and under some conditions they can contribute that building block of protein to the system at large. Persistence of that part of the plant community contributes a blanket of long lived minute plants that hold soils in place as long as they are not ground away by the hooves of concentrated herds of stock.

More significant rainfalls stimulate activity of the vascular plants allowing them to take up soil nutrients, fix carbon and invest in growth and reproduction in addition to maintaining themselves. Significant rainfall in the right time of the year will send a message to the seed bank waiting in the soil and elicit germination of a portion of its stores. On rare occasions, perhaps every decade or so, enough rain will fall to trigger trees and shrubs to divert energy and resources to making very large crops of seeds. In such good seasons if there are not an overwhelming number of grazing animals to take the seedlings as they become established, the next major generation of woody plants will be launched. If significant rainfall does not come, ephemeral plants may not germinate, may appear in the form of only a few individuals or may start growth only to burn off in the dry weather that follows. Little food is then provided for grazing animals. They must turn to the perennial vegetation or leave the area.

Much of the perennial woody vegetation presents challenges to the herbivores trying to live on its leaves and stems. Thorns and other deterrants are often present. Sometimes the leaves concentrate salts or nitrogenous compounds that are toxic to herbivores if eaten in large quantities. If the salty leaves and stems are eaten extensively, then the animal will have to find water to drink to rid itself of the salt. Watering points for domestic stock may provide that water. If the water is not available, then the salty food cannot be eaten. For most of the grazing mammals surviving on this kind of vegetation, outlasting the drought is a waiting game in the face of a negative protein balance. A short drought is survivable on this diet. A long drought may not be for either the stock or the perennial shrubs being browsed. Too many stock kept in a pasture through too many droughts will eventually eat out this vegetation. The native grazers, the kangaroos and their relatives, are offered the same base of resources as the domestic stock. They, along with the sheep or cattle, wait for the end of the drought. If they are fortunate, they survive the times of food and water stress to welcome the returning rains and plant growth that follows or unlike the sheep the native wildlife may move in search of green food elsewhere where the conditions are better. If they are unfortunate and the drought lasts too long, they perish. The local area must then await reoccupation by animals coming in from another area. This pattern of high drought frequencies in a stressful environment provides a background conducive to local extinction of populations of wildlife species. Such has probably been the pattern for many populations for thousands of years. What has changed with pastoral development is the increased number of animals dependent on the same categories of food resources, fragmentation of the resources through their overuse and barriers to the movement of animals between patches of habitat capable of supporting them. When local extinction of a population persists and the phenomenon of local extinction becomes widespread throughout all of the populations of a species, the risk of local extinction of populations can become transformed to risk of loss of all the populations, species extinction. This process is likely to underly the loss of roughly half of the medium sized species of mammals described at the time of early settlement in Australia.

The story of the Australian fodder grasses is similar to that of the woody perennial vegetation. The original grass communities on which the first European settlers pastured their sheep were never documented by biologists. Their species composition is unknown. However it is probably safe to infer that the most palatable of these grasses were eaten first by the sheep and that some of these grasses are now rare or missing in sheep paddocks today. One of the grasses, speargrass, that the early settlers viewed with alarm, increased its presence in the late 1800's. The awns and sharp armor of the speargrass seeds sometimes caused great damage to the sheep. The problem of speargrass caused the redevelopment of a breed of African sheep to withstand these hazards. Today, the speargrass is a major arid zone grass species and a mainstay of sheep pastures. This is partly due to the relative resistence to grazing of the speargrass. Even so, grazing exacts a large toll. Under heavy grazing pressure the speargrass has to replace its leaves as they are eaten. Leaves are necessary to photosynthesis and photosynthesis permits the plant to establish its root system, increase its size and mature sufficiently to produce seed to found new individuals. When leaf replacement is a major resource drain on the plant, few reserves are stored. Additional grazing pressure and drought conditions may cause the death of the plant. When this occurs on a large scale the perennial habit of the grass is transformed to an annual pattern within the population. Speargrass then joins the ranks of the ephemeral plants. It is no longer available to herbivores throughout a drought, it no longer serves to hold the soil in place between crops of grass. It is also unable to take advantage of each of the windows of time that offer good growing conditions because each year it has to begin again to establish its roots and leaves anew instead of adding to its previous growth. When speargrass is fenced off and protected from grazing it is able to continue to grow throughout even severe droughts. On grazed plots experiencing the same drought conditions, the grass plants are unable to survive both the stress of drought and of depredations by herbivores. The plants die and must be restored to the area by germination of seed. This may be the key to the success of the great many species and large biomass of immigrant ephemeral plants to Australia whose origins are in the Mediterranean region. These plants probably arrived with European pastoral development. They have experienced 8,000 years of grazing by domestic stock and are adapted to coexistence with sheep and cattle even if they are not adapted to the rigorous aridity and nitrogen-poor soils of Australia. Inside the fenced speargrass plots, the native grass is able to claim more and more of the ground away from the introduced species. In the absence of grazing it is a successful competitor when grown under the conditions of the Australian climate persisting and growing each year. The balance is shifted by heavy grazing in favor of annual grasses and the ephemeral herbs which do not contribute to the stability of the system during the times of climatic stress.

The solution to the merger of long term development of the pastoral industry in Australia and survival of the productivity of the natural system would come as no surprise to Charles Lindbergh. To stabilize production and, over the long run even increase it, management protocols need to approximate the natural ecological system and remove no more resources than the land can produce as interest developed from its biological capital. Numbers of herbivores supported must be tied to the carrying capacity of the land at its least productive times. Large areas are needed as management units for stock so that subunits of land can be rested to allow renewal of perennial vegetation. Infrequent times of high rainfall can trigger setting of seed in woody plants. Subsequent protection of the young seedlings from stock is necessary to allow recruitment of the next generation of shrubs and tree. If the drought is only local, large management units also make possible movement of stock within an extensive area to pastures of relatively higher rainfall where ephemeral plant communities can support the herd.

Sound pastoral practice has immediate benefits to wildlife as well as to the stock and stockmen. Whatever enhances and protects productivity of the dry rangelands benefits both pastoralism and the native wildlife which can then fit into the interstices of the development.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 68–72, March 1986

Sea and Space: Frontiers for Exploration—an Introduction

Sylvia A. Earle

Vice President, Deep Ocean Technology, Inc.

". . . The only other place comparable to these marvelous nether regions, must surely be naked space itself, out far beyond atmosphere, between the stars . . . where the blackness of space, the shining planets, comets, suns and stars must really be closely akin to the world of life as it appears to the eyes of an awed human being in the open ocean, one half mile down."*

The human body is remarkably versatile, able to climb mountains, swing among treetops, swim considerable distances, leap into the air, and briefly enter underwater realms. We are not naturally equipped with wings to fly nor gills to remain for prolonged excursions in the sea. By using something we *are* endowed with—ingenuity—we have been able to respond to and in some measure satisfy another human characteristic—irrepressible curiosity. The result has been the creation of a gradually expanding wealth of technology that serves to extend human capability, even into environments inhospitable to any life form.

To some, "technology" conveys the spectre of an overly mechanized society, a loss of contact with nature, a spoiler of civilization. Charles A. Lindbergh felt that a balance is possible, that the human passion for creating and using tools can be compatible with maintaining a healthy environment. The use of technology is, in fact, necessary for access to space and to the deep sea. Without machines to take us into the sky, we would be as earthbound as elephants; without submarines and other special diving equipment, our ability to explore the oceans directly would be approximately equivalent to the ability

*William Beebe, *Half Mile Down.*

of dolphins to glimpse the above-water realm.

There are parallels in the development of the technology that has made possible the exploration of space and the oceans. Until about a century ago, both were experienced primarily through remote methods. Telescopes magnified the view of astronomers, but flight was a dream prior to Lilienthal's first successful piloted gliding flights in 1881–1896. When the British research vessel, *Challenger* undertook to explore the oceans of the world in 1872, scientists aboard used nets and dredges and other devices to blindly sample the oceans. Imagine trying to understand the workings of a forest or city if the only information you had to work with came from fragments fortuitously snared from a sky-ship?

Five years after the Wright brothers made their first powered, sustained and controlled airplane flights near Kitty Hawk in 1903, the British Royal Navy deployed the first diesel electric submarine.

Technology designed to master both skies and seas came together in 1911 when Eugene Ely flew a Curtiss Pusher and touched down aboard the cruiser, U.S.S. *Pennsylvania* in San Francisco—the first landing of an airplane on a ship.

The early 1920's marked numerous events of historic consequence for aviation including Lt. James H. "Jimmy" Doolittle's transcontinental flight in a single day (Pablo Beach, Florida to San Diego, California). Meanwhile, British inventor, Joseph Peress, built the first successful armoured diving suit, later known as *Jim.*

The "Kitty Hawk" of rocketry occurred in 1926 when Robert Goddard demonstrated the successful operation of a liquid fuel rocket, and two years later, Fredrich Stamer made the first flight of a manned rocket-propelled airplane. During the year between these events, Charles A. Lindbergh flew from New York to Paris, the first solo non-stop crossing and the first by a single engine aircraft.

Balloonists A. W. Stevens, W. E. Kepner and O. A. Anderson set a new altitude record—60,613 feet aboard the *Explorer I* during the same year that William Beebe and Otis Barton set a new depth record—3,028 feet in a bathysphere designed by Barton and deployed offshore from Bermuda. The following year, 1935, diver Jim Jarrett wore the diving suit that bears his name and located the vessel, *Lusitania,* sunk in 330 feet of water off the coast of Ireland.

The half century that has transpired since these events has been an era of unsurpassed technological development, dramatically evidenced in the rapid progression of critical developments leading to manned and robotic aircraft and spacecraft. The first successful helicopters, first jet flight, and first passenger plane with a pressurized cabin, Boeing's 307 Stratoliner, all occurred before 1940.

In the following decade, regularly scheduled commercial aircraft began transatlantic service, Captain Charles E. Yaeger became the first pilot to exceed the speed of sound and Jacques-Yves Cousteau and Emile Gagnan perfected the aqualung and used it to dive to 210 feet in the Mediterranean Sea. Balloonist Auguste Piccard turned his attention to the oceans and, in 1948, with Max Cosyno, tested his subsea "balloon," the bathyscaphe *FNRS2*.

The 1950's marked records of depth (13,287 feet in the bathyscaphe *FNRS3*), distance (U.S. nuclear submarine *Nautilus,* Pacific to Atlantic under the North Pole), and speed (Mach 2 by A. Scott Crossfield; Mach 3 by Captain Milburn Apt). It was the decade that marked the launching of the first remotely operated vehicle into the sea. It was also the decade that signalled the dawn of the space age.

Sputnik 1, the first man-made earth satellite, was placed in orbit by the Soviet Union. By the end of the decade, the U.S. had launched a successful satellite (*Explorer I*) and the Soviet Union landed the first man-made object on the moon, *Luna 1,* and photographed the farside of the moon for the first time, using *Luna 2.*

New frontiers were attained at an accelerating pace during the ten years that followed. Underwater highlights include a descent to the ocean's greatest depths, 35,800 feet, in the bathyscaphe, *Trieste,* by Lieutenant Don Walsh and Jacques Piccard in 1960. That same year, the U.S. nuclear submarine, *Triton,* completed the first round-the-world cruise underwater—30,752 miles in 61 days. Skyward, the first weather satellite, *Tiros I,* was launched.

Major Yuri Gagarin became the first man to view earth from space in 1961, and later that same year, Alan Shepard, Jr. became the first U.S. astronaut to enter space. A year later, Lieutenant Colonel John Glenn orbited earth aboard the Mercury spacecraft, *Friendship 7,* and *Mariner 2* became the first spacecraft to conduct a fly-by of another planet (Venus).

Edwin A. Link, well known for his pioneering work in aviation, turned to ocean exploration in the early 1960's and, concurrently with Jacques Cousteau and U.S. Navy Captain George Bond, pioneered the techniques of underwater living—saturation diving. While some men were living underwater in the mid-1960's (*Sealab II; Conshelf III*), others were walking in space (*Voskhodz; Gemini 4*). In 1969, while a team of four men occupied the underwater laboratory, *Tektite,* fifty feet down, three others ascended to the moon.

Eleven successive five-person teams spent fourteen to twenty days saturated in the underwater habitat, *Tektite.* By the time the last *Apollo* crew visited the moon in 1972, twelve men had left their footprints there.

Throughout the 1970's, advances continued to occur concerning access to space, despite significant funding cut-backs. The U.S. *Skylab* crew rendezvoused in space with the *Skylab* orbital workshop and later, *Apollo-Soyuz* marked the first international manned space mission. In 1977, the *Salyut* space laboratory was launched by the Soviet Union and, in due course, was occupied for as long as 139 days. Also in 1977, Paul MacCready's *Gossamer Condor* achieved sustained man-powered flight, following rigidly prescribed guidelines to win the Kremer Prize. The same year, the spacecraft *Voyager I* was launched by the U.S. to fly by Jupiter, Saturn, and beyond, carrying greetings from many nations as well as hauntingly beautiful songs of humpback whales.

In the 1970's, groundwork was established for a series of *Space Shuttle* missions in the 1980's, that in turn were designed to lead to a manned *Space Station* before the end of the century. National support for ocean technology and research in the United States declined during this decade, but the increasing demands for ocean access by the offshore oil and gas industry provided worldwide incentive to develop new technology. Numerous small submersibles appeared, mostly for industrial applications, and saturation diving techniques were pushed to new limits. In 1972, the French company, Comex, conducted a simulated dive to 2001 feet, and working dives in the North Sea to 1000 feet became almost routine. Atmospheric diving suits, including fifteen modernized *Jim* systems and more than thirty other small one man units called *Wasp* and *Mantis* came into being.

Nineteen seventy-nine provided an opportunity for me to evaluate the atmospheric diving system, *Jim,* for scientific research in the clear, blue waters offshore from Oahu, Hawaii. As I descended to the sea floor to 1250 feet (Figure 1), I was aware of some of the striking similarities between my situation and that of astronauts, while acknowledging the vast technological and economic differences.

Although the original *Jim* design was developed in the 1920's, modern versions look remarkably similar to equipment used by astronauts, and for good reasons. In space as well as in the sea, it is necessary to take along life support for enough time to sustain you while you accomplish your mission. Exposure to the pressureless vacuum of space would affect humans in a way different from exposure to 600 pounds per square inch of pressure exerted at 1250 feet or more, but the end result would be equally fatal. In both kinds of protective suits, movement is awkward. Astronauts

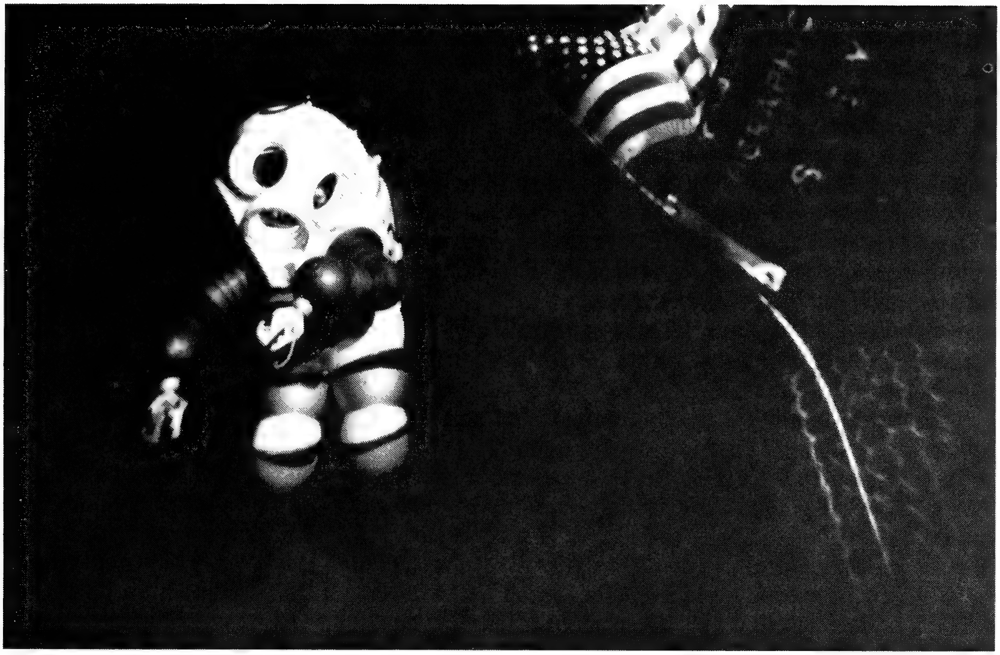

Fig. 1. Dr. Sylvia A. Earle descended to a world-record 1250 feet in 1979 offshore from Oahu, Hawaii in an atmosphere diving system called *Jim*.

slip their arms and legs into moderately flexible covering; *Jim* is made of a magnesium alloy, weighs half a ton, and uses articulated rings joined by special oil-filled seals.

In space, astronauts are alone, aside from human companions who might have come along, and flora and fauna deliberately or inadvertently associated with the spacecraft. In the sea, there is no such thing as "alone." Walking along the sea-floor, the abundance and diversity of life is dazzling. Red swimming crabs, small fish illuminated by rows of glowing lights, rays longer than I, hovering like giant butterflies; tall spirals of bamboo coral that shimmer with blue, luminescent fire when I brush against them . . .

This, I reflect, is why we must look inward to the sea, while simultaneously pushing the frontiers skyward. This is a planet brimming with life, most of it concentrated in the ocean. In curious, dimly understood ways, our survival, our well-being, is linked with theirs. The history of life is in the ocean, written in the lives of millions of jewel-like creatures that we have barely begun to catalog, let alone understand.

What is holding us back? During a time when passengers fly seven miles overhead, watching movies and eating lunch, why does no nation possess even one vehicle, manned or not, that is capable of travelling to seven miles into the sea, something accomplished in 1960, and not once since.

Why, in the mid-1980's, more than a decade after the last astronaut walked on the moon, are there still more footprints there than there are a half mile underwater? Is it thought that the oceans are already thoroughly explored? Is it imagined that the dangers underwater exceed those in space? Will exploration in the sea by divers and manned vehicles give way to robots? Will future space exploration be left largely to machines that are lofted skyward and monitored thereafter by vicarious, earth-bound explorers?

Will Space Shuttle astronaut Katherine

Sullivan,* a marine geologist who has been lured skyward, have her way and be able in the future to work in space with machines, rather than be replaced by them? Will there still be room for the spirit that characterized past explorations to thrive as the new frontiers in sea and space are approached?

Anne Morrow Lindbergh was asked to comment on the perils ahead, prior to departure with her husband on the first over-the-arctic flight to establish the practicality of travelling from New York, "north to the orient."

One reporter said:

"Can't you even say you think it is an especially dangerous trip, Mrs. Lindbergh?"

She responded:

"I'm sorry. I really haven't anything to say. (After all we want to go. What good does it do to talk about the danger?)"

The presentations that follow will acknowledge the dangers, the risks and commensurate rewards associated with exploring the frontiers of sea and space. Two concurrent themes will be repeated, sometimes softly, sometimes quite distinctly:

"Onward and upward . . . and onward and downward!"

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 72–76, March 1986

Research and Development of Resources in Space

Walter Cunningham

President, The Capital Group

The focus of the Lindbergh Fund's efforts is the creation of harmony between technological innovation and the environment. Sometimes the two are in conflict. Technologists may look at the question from a slightly different perspective than environmentalists do. That statement "technology and harmony with the environment" raises the question of balance between the idealistic and the pragmatic. Frequently there is an overworked effort to blame technology for today's problems. I believe that we should also give technology credit for solving some of yesterday's problems. For example, I recall reading an article that pointed out that in the year 1805, 2,000 people were employed in the city of London whose sole job was to sweep a path across the street through the horse manure from all the horse-drawn carriages that were going through town. The potential hazards were not just the smell and inconvenience, but the diseases that could be transmitted by the flies. I think that there are a lot of us that would just as soon not go back to that

*Dr. Sullivan's presentation, "Technology for Exploration of Space" was cancelled by NASA due to the Space Shuttle *Challenger* accident.

kind of a pastoral environment. Certainly technology has moved us away from things like that throughout history.

Just imagine the problem today if we were still trying to maintain our reasonable standard of living with live horses instead of the mechanical and electrical horsepower that we use today. In addition to the enormous health hazards, the horse/rider accident rates would project to be ten times higher than what we are having today with today's modern technology. If we are looking at today's technology as creating some problems let's also give it credit for solving some of yesterday's problems. I am very optimistic that tomorrow's technology will solve whatever problems we have today or whatever we are creating for today.

As a question of balance, people sometimes forget that in going after what they want, the needs of everybody else may not be met. This issue is sometimes framed as a quality-of-life problem. It is also a quantity problem. We probably are in the fix that we complain about today, because technology has enabled an increasing population to use up the shrinking resources of our planet at an ever increasing rate. How do we improve upon that? First we can introduce a more efficient utilization of those resources. Less waste. For example, turning waste products into useful resources or at least minimizing the waste. Second, we can try to find more resources. That's going on all the time but it is becoming more difficult and more expensive to find those resources. Third, we can control population growth—the most significant controllable factor.

Space exploration addresses the quantitative aspects of the resources problem. There are a lot of people who see moving into the space environment as a way of tapping new resources. With many processes, it offers greatly increased efficiencies, a few examples of which will be given later. Some things can be done a lot better in a micro-gravity environment than it can be done down on Earth. And outer space is certainly not as crowded. Space is where our future is. We are filling up this planet. That new ocean is more pristine now than the New World was before Columbus and Magellen. We've been out there for 25 years and we have just stuck our toe in that particular ocean. And that's an ocean which Charles Lindbergh would enthusiastically support exploring today.

Our space ocean, the one that we are moving out into, is the most hostile environment that man has ever explored. The exploration of outer space requires the most complex systems ever devised and operated by man if we are to safely move into that environment. We have been exploring it 25 years but we have just begun. We have not yet begun to exploit space for man's benefit yet. We are still at the cutting edge of trying to routinely get there and survive. The space shuttle, in fact, is the first step in that direction. It's the vehicle that we are committed to in this country to utilize as our means of commerce into that new ocean for the next ten years.

When I talk about exploiting our movement into the space environment—I'm not talking about mining asteroids, lunar construction sites, nor space colonies. I am talking about what we can do in the near term. How do we create an efficient free-market system for a society like ours in order to utilize the space environment? We are spending a lot of money on it. In a government-controlled economy, such as the Soviet Union, the leaders can do whatever they want about exploiting space. There is no need to meet free-market tests. I personally don't think this is the best way to spend money through a government-controlled economy. Government-controlled efforts at commercialization do not have a good record in the past. I do not think that they will be able to change that record in the future. Government efforts to sponsor commercial technology, for example the nuclear-powered U.S.S. *Savannah,* Operation Breakthrough in housing, the Synfuels Corporation, the *Concorde,* the *TU144*, are certainly not economic ventures. Those were all government-funded projects. Government has been somewhat more successful in brands of generic research such as aviation research.

In free economies, government spending is a debatable subject and it's subject to public pressure. That means that it is impossible to commit funds arbitrarily. The help of private enterprise is needed to take up the slack. A profit motive is essential if private industry is to accept such a challenge.

There are various categories of commercial participation in the space environment. First, in the aerospace industry private companies develop rockets, space infrastructure, power systems, space facilities, space labs, and industrial space.

A second level of private industry participation is technology transfer. Technology transfer for space exploration is not much different than the classical technology transfer from any new field. I hesitate to mention it because it has always been somewhat embarrassing to stand up and talk about Teflon frying pans and beta cloth which the public tends to appreciate as having flown out of the space program. We should not lose sight of the fact that space technology transfer has been beneficial in other areas, for example the inertial navigation system of the 747. A 747 can take off from Orlando airport and operating purely on that inertial navigation system, the pilot can fly to the final approach going into Honolulu, Hawaii, probably to within a half mile of the final approach path. That inertial platform has three such units on the 747 for redundancy and to correct any errors. They have to be cheap enough such that it is economically feasible to put three of them on board. They are only cheap because the same contractor that sells those inertial platforms for the 747 was the one that developed the inertial platform and the navigation system for the *Apollo* spacecraft back in the early 1960s. This is a natural exploitation of technology that was developed for one purpose and then diverted to be used in other places. The problem with that in the long-term commercialization of space is its reactive nature. Recognizing that technology is available, matching it up with a market demand, and putting it to other use is good for business, but it does not place an initiating demand on space exploitation itself.

The third area, and the only one that offers long-term potential for us to succeed in this environment, is exploiting the unique properties of space in order to either manufacture products or to improve processes for the marketplace here on earth. The customer for that type of development is the commercial marketplace. Government in the last ten years, NASA explicitly, has been marginally successful at encouraging this type of commercialization.

The government and the marketplace are sometimes in conflict. For example, if the aerospace industry wants to create a new booster, they would like to see the government cost of that booster as high as possible. On the other hand, in order to exploit the unique properties of space we need to have the cheapest transportation system possible to get into and out of orbit so we want the lowest priced booster transportation. The most frequently used example of commercial exploitation is the McDonald-Douglas experiment on electrophoretic separation which has been done on about four shuttle missions. This process is based on the separation of different hormones by virtue of their electric charges. McDonald-Douglas has expended about 15 billion dollars so far in that area and there is hope that some of the products of the process will have a sale value. They claim that this separation of hormones is about 700 times more effective in zero gravity than it is on the ground. In addition, the end product is about four times as pure as with other separation processes.

What are the properties of space that we can exploit to make a market-driven space economy? First, there is a cost-free, micro-gravity environment. When you start comparing space microgravity with what you can do on Earth, the best scientists have been able to do is the drop tower in which they can let something free fall about 10^{-5}g for four seconds. Or they have been able to fly in parabolic trajectories in an aircraft up to 30 seconds of 10^{-2}g. That's about one one-hundredth of a g. So far, we have probably conducted less than one hundred hours of active experiments in this micro-g environment. So we have hardly begun to exploit some of these properties.

Other, not-so-frequently thought of important properties of this environment are its near-perfect vacuum, its near-perfect sterility, its extremely cold temperatures, (the temperature outside is almost −273°C), the full electro-magnetic spectrum of radiation, and unobstructed fields of view. Most of the good things that come out of these new areas come serendipitously. If we only plan to look for those we know, we will probably miss the most important new ones.

Taking advantage of these particular properties will lead to a commercial market in zero gravity, estimated to cost between 50 billion and 150 billion dollars by the year 2000. We have to be moving continuously in that direction but there are a lot of obstacles. Most notable is the economics of doing it. Back in the days of *Apollo* when I flew, it cost about $1,000 a pound to go into orbit. When they started to design the space shuttle, they were trying to come up with a system that could reduce that by a factor of 10 which would have meant $100 a pound. Well, everything that I read lately says that it has been estimated to run from $1,600 to $5,000 a pound for the space shuttle to put it in orbit. If you convert that back to 1971 dollars, we're talking about $650 to $2,000 depending on how you do your arithmetic back there. Frankly, it looks to me like in the 15 years or the 20 years since *Apollo,* we are just about holding our own, certainly we have not cut costs by a factor of 10.

General Dynamics has estimated it would take a $10,000 per pound price tag in order to make it economically worthwhile to sell something that was made in space. In another study, McDonald-Douglas has estimated that it cost 31 million dollars per shuttle launch, which is the early price tag for an *Apollo* launch. The whole subject of what should be charged for a launch on the space shuttle is now up for discussion. There is a wide range of opinions on the issue. The proposed charge now is 87 million dollars but private industry has indicated that the figure ought to be about 137 million dollars. So even with this issue there is conflict. I believe that we cannot afford to raise the price of a launch even to 87 million dollars. There are some things which only the government can do. One of them is having a space program, and providing a transportation system into and out of space.

We have stiff competition. The French are charging $3,000 per pound to put satellites up on their rockets. Launch services have been offered by the Soviet Union and China has opened an office in Washington, DC to sell commercial pay loads on their rockets. Brazil, India, and Japan are considering doing the same. The point is that we have to remain competitive. Those governments and those economies are able to subsidize the cost of their launches. If we are going to compete we are going to have to subsidize launches and reduce transportation costs.

One of the candidates for the third generation of semiconductor materials is indium. It has been estimated that defect-free indium which could be produced in zero gravity (microgravity) would sell for $450,000 a pound. This is an example of a high value, low volume, low weight product that will meet the cost criteria. If launch costs could be reduced to $100 a pound, it could facilitate the creation of a free market on products produced in space.

There are a few issues with which we need to be concerned for the future. One of them is a perceived lack of reliability on space shuttle flight schedules. Certainly the *Challenger* explosion doesn't enhance the image in that direction. There's a suspicion on private companies' part about government involvement in commercial ventures. Policies can change, they change with the politicians. What is a long-term commitment? What kind of tax breaks? You know right now you can't take an investment tax credit for something that's done in orbit because it has to have been used six months out of the year, here in the United States. There are a number of policies that need to be changed, some of which there's no argument about, but it's still subject to political whims to have it happen. There is also the problem of insurance costs. You have been reading about them every time something goes wrong. I understand that the insurance company that paid for one of the satellites that they brought back, still haven't found a customer to buy that satellite. It's certainly a problem that holds back some of the commercial exploitation.

Finally, but not least, and maybe even one of the stickiest ones is the subject of intellectual property. What kind of proprietary rights do you have when you are using a government-subsidized launch vehicle? I think that this question can be addressed rationally, however, it means changing some policies about government ideas on intellectual property and that doesn't come easy.

Well, none of those problems are trivial. They are all being addressed. They haven't discouraged a whole raft of companies, McDonald-Douglas, Rockwell International, 3M, General Electric, Union Carbide. There are a lot of companies working on the commercial development of this new environment. One of the areas that has not really been opened up yet, one that I believe very strongly in, is entrepreneurial participation. We have all seen in the past, that the businesses that really make it big in some new field may not come out of the large corporations. Certainly the aerospace companies that should have a leg up on all this knowledge about space have not come forth with great new commercial ventures. McDonald-Douglas seems to be making an effort. But, I think we need to find a means for entrepreneurs to take advantage of this environment.

I really only need to emphasize that my discussion here was intended to frame some questions in your mind and give you some information; certainly it's challengable. I think the analogy of setting sail on this particular ocean in space is an absolutely marvelous one. I will leave you with a quote by Arthur Clark that I really love. Arthur Clark several years back said, "We have set sail on an ocean whose farthest shores we can never reach."

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 77–81, March 1986

Policies for Exploration and Use of the Oceans The Discovery of R.M.S. Titanic

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ABSTRACT

The discovery of the sunken luxury liner Titanic on the floor of the North Atlantic Ocean in the Summer of 1985 in a French-American cooperative effort not only highlighted the dramatic use of deep ocean technology, but also raised significant policy questions for oceanographic research. Our ability to protect the resting place of Titanic will reflect our ability to manage the exploration of the oceans effectively, to protect their natural environments, and to successfully negotiate agreements to that effect with other nations.

She was the finest, most magnificent ship ever built. Nothing like her had ever been attempted before, and nothing quite like her has, I think, been contemplated since. She carried the rich and famous, the aristocracy of Europe and America; the Strausses, the Astors, J. Bruce Ismay, President of the White Star Line, and Thomas Andrews, her builder. She was the latest state of the art, the leading edge in ship building, the most high-tech ship of her day. Every eventuality had been seen to, she carried every convenience, every accoutrement imaginable, including lifeboats for more than a third of her ship's company, exceeding the requirements of the British Board of Trade.

On her third day at sea at 11:40 p.m. she grazed an iceberg that sliced a 300 foot gash in her starboard bow flooding all of her forward water-tight compartments. In less than three hours she had settled to the bottom of the North Atlantic, more than two miles down, near a deep sea canyon.

It was unimaginable, her going down that way, with her stern pointing vertically skyward against what Walter Lord called a "Christmas card backdrop of brilliant stars". She slid so slowly beneath the waves that the ship's baker stepped off her fantail as she went down like getting off an elevator. He didn't even get his hair wet. She had been the ship that "God Himself" couldn't sink, and now in two hours and 40 minutes it seemed as if "God Himself" had done exactly that.

When *R.M.S. Titanic* went down in April 1912 she took with her 29 boilers, coal enough for burning 650 tons a day, 5 grand pianos, assorted bottles of ale and wine, chamber pots, serving platters, 30,000 fresh eggs, a jeweled copy of the Rubaiyat of Omar Khayyam, an entire way of life, and one thousand five hundred human souls.

It was on this very spot 73 years later that a small French research vessel out of Brest began a series of searching sweeps, criss crossing a 150 square mile target area of the ocean bottom. In August, after having covered 80% of the target, *Le Suroit* turned over the search to RV *Knorr* out of Woods Hole which took her turn at the monotonous procedure the technicians called "mowing the lawn". Below *Knorr* in the inky blackness was *Argo,* a towed sled on a 13,000 foot tether of cable feeding a television picture to monitors on the mother vessel more than two miles above.

She had been on station for 10 days. In the lab, French Oceanographer and Co-Chief Scientist, Jean-Louis Michel had just relieved his American counterpart, Dr. Robert Ballard at the monitors, sending Dr. Ballard to his cabin for a much needed shower and rest. The rest was short lived. Ship's cook, John Bartolomei, knocked on the door to inform him that something was going on in the lab that they wanted his opinion on. Something going on in the lab. He was to remember thinking that it was odd that they had sent the cook and not one of the technicians to roust him from his bunk. It was a disturbing departure from routine and he pulled his jump suit over his pajamas and made his way to the lab with more than his usual haste. In the lab amid a growing and excited group he peered into the monitor's blue white flickering image of bolts on the side of a boiler, and knew where he was. After 73 years, *R.M.S. Titanic* had been found.

The first order of business was to relocate the bottom transponders so that *Knorr* could hold her position over the wreck. *Argo* was then retrieved for servicing. In the process a winch gear was broken off and it took ship's engineers 14 hours to jury rig a replacement. Dr. Ballard gathered his exhausted exhilarated technicians on the stern where he held a brief memorial service for those lost at sea 73 years before. What followed was hours of frantic imaging, flying *Argo* around *Titanic's* stacks and bridge in a series of daring and nerve-wracking close-up maneuvers which twice collided *Argo* with *Titanic.* He was later to look down and realize that after 40 hours on watch he was still wearing his pajamas under his jump suit.

Like most scientific discoveries this one took place by standing "on the shoulders of giants". It took astute interpretation of 73 year old data, accepting some, discarding some, to finally select a 150 square mile area for the search. *Le Suroit* began in July the lawn mowing procedure crossing the area with their revolutionary deep-search sonar and magnetometer vehicle the "SAR" which can survey a swath of ocean bottom more than a half mile wide with each pass. In heavy seas and gale force winds *Le Suroit* and *Sar* eliminated the bulk of the search area making possible the American follow-up in August and September.

The American equipment differed dramatically from the French. Both were submerged unmanned bodies connected to the main vessel by a long cable. The Woods Hole submersible was called *Argo* after the name of the mythical vessel that carried Jason on his quest for the Golden Fleece. *Argo,* like *Sar,* contained sonar gear, but more importantly it carried three cameras with the capability of telemetering their images back to the surface where observers can sit in relative comfort (all comfort at sea being relative) to watch in real time on the monitors what the cameras were "seeing" down below. *Argo* is towed close to the bottom, depending on the ruggedness of the terrain and the courage of the technician and winch operator who operate in the full knowledge that a collision that results in the loss of the vehicle will terminate the expedition promptly. This procedure is called "flying" the vehicle. Fortunately *Argo* has operators with just the right touch so that it can work the bottom for over 70 hours in a single stretch without catastrophe. *Argo,* like *Titanic,* was on her maiden voyage at the time of the discovery, but even with very sophisticated gear, worked perfectly.

Knorr does carry another submersible sled called *Angus. Angus,* which has been used in earlier work on the discovery of undersea vents and unusual deep sea animals, does not carry video imaging capability. It does carry sonar and 35 mm film cameras, but without video, the operator is in effect shooting blind, hoping his cameras are pointed in an interesting direction. Most of the slides taken of *Titanic* were taken with the *Angus* system, but only after the terrain and wreck were carefully surveyed and locked into the shipboard computers. It is the aforementioned bottom transponders which are essential in this very tricky operation. It is the time difference in the arrival of key points of underwater sound between the transponders placed on the bottom and on *Argo* which permits the calculation of distance to each object and thus later allows for the positioning of *Angus* for picture taking: a very tricky business indeed (see sketch, Figure 1).

The *Titanic* was found sitting upright in rolling sand dune country with very little cover of sand or mud and very little marine growth. Not far away is a deep sea canyon which could have tumbled the wreck over itself destroying much that was identifiable. There had been much speculation prior to the discovery postulating much greater disintegration and coverage of sand and mud or even that she might be deeply

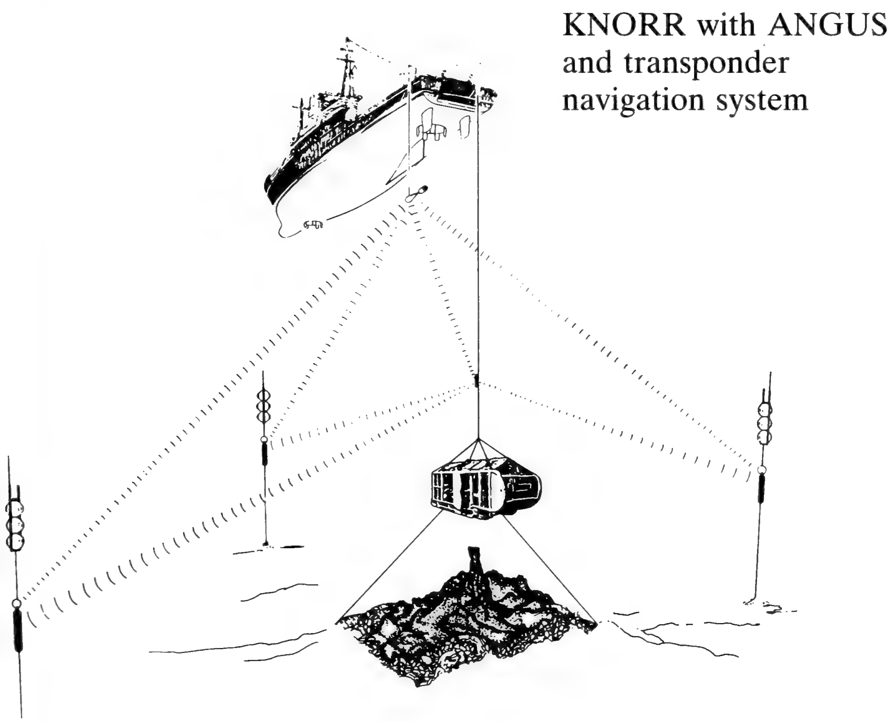

Fig. 1.

buried in a muddy bottom. Fortunately these speculations turned out to be wrong. *Titanic* has lost two of her giant smoke stacks, and the stern section has parted from the rest of the wreck, but the remainder of the hulk is in amazingly good condition.

The photographs of the *Angus* probe resulted from the computer calculated positions of earlier data secured by *Argo's* video system. That they got pictures at all is one of the most amazing parts of the story, but then these are selected from over 10,000 shots. This is after all the secret of all great photography; knowing that you cannot shoot too much film.

It has been known for some time that ships on their way to the bottom leave a characteristic debris plume; essentially a collection of material that settles to the bottom on one side of the wreck. *Titanic's* debris field extends about 800 meters aft of the wreck. It includes a number of artifacts that have only begun to be cataloged.

We are concerned here, of course, with questions of Ocean Policy, and in fact the political and philosophical questions are likely to prove more lasting and complicated than the scientific ones. It is well known that the *Titanic* disaster resulted in a number of immediate policy changes. It changed many rules of the sea relating to safety and navigation in northern waters, particularly during the iceberg season. Almost immediately shipping routes were shifted several hundred miles to the south. The International Ice Patrol was created as one of the most important results of the tragedy. The foundation of the Woods Hole Oceanographic Institution was indirectly a result of the early work of the Ice Patrol which convinced Henry Bryant Bigelow and others of the need for an oceanographic institution on the East Coast. The irony that this Institution should eventually participate in the rediscovery of the Titanic wreck is an additional twist on a story that is laced with irony. The Patrol, supported by several nations, was originally housed at the Oceanographic in Woods Hole, and a great deal of cooperative oceanography was the result. The Patrol annually plots the field of ice, as well as the approach of rogue icebergs to the active lanes of shipping in the North Atlantic.

It is a further ironic twist to the *Titanic* story that the wreck itself must be protected from the very technological break throughs that made its discovery possible. The knowledge that locating the wreck was possible has awakened the curiosity and greed of souvenir hunters around the world. Protecting our environment (either natural or archaeological) from the uncontrolled expansion of our technology is, after all, one of the themes of this symposium, and may well be the dominant moral problem of our age. How does one put the technological genie back in the bottle, or at least, in this case, how does one prevent its unscrupulous use by developers? The laws of ownership have not changed for several centuries, and this leaves open the policy question of who, if anyone, owns the Titanic.

There are several possible legitimate claimants to the wreck. The original owners, The White Star, now the Cunard Line might make some claim to it, but have yet to do so. Their successors-in-interest the Commercial Union Assurance Society could lay claim by virtue of their having paid the insurance on Titanic, but only if they can prove that the wreck has not been abandoned, an unlikely prospect. WHOI and IFREMER could make a more plausible claim to at least some of the value of any salvage, by virtue of the excellent work they performed in discovering the wreck.

The current proposal, however, is to leave the wreck untouched and to declare it an international maritime memorial for those who died there in 1912. The House of Representatives has passed such legislation, which requires the American Government to enter into negotiations with other interested powers, primarily Great Britain, France, and Canada. The difficulties associated with getting even countries who are allies to agree to a protectionist plan are difficult to estimate. Getting the Western Allies to agree on anything these days is a mountainous task.

However, the stakes are great. *Titanic* is magnificent where she lies, and should be protected from those who would tear her apart, as vigorously as we would protect an endangered natural resource. Furthermore, although the likelihood of anyone successfully raising her is remote in the extreme, the possibility of reckless salvagers dying in the attempt is real. The ultimate tragedy would be for any more seafarers to die on *Titanic* than those who now lie in watery graves off Newfoundland.

We all have a stake in the preservation of the Titanic Memorial so that the lessons learned and paid for at so dear a price will not be lost to future generations. We have seen in pictures the extraordinary preservative powers of the deep sea. We are called upon to do no less.

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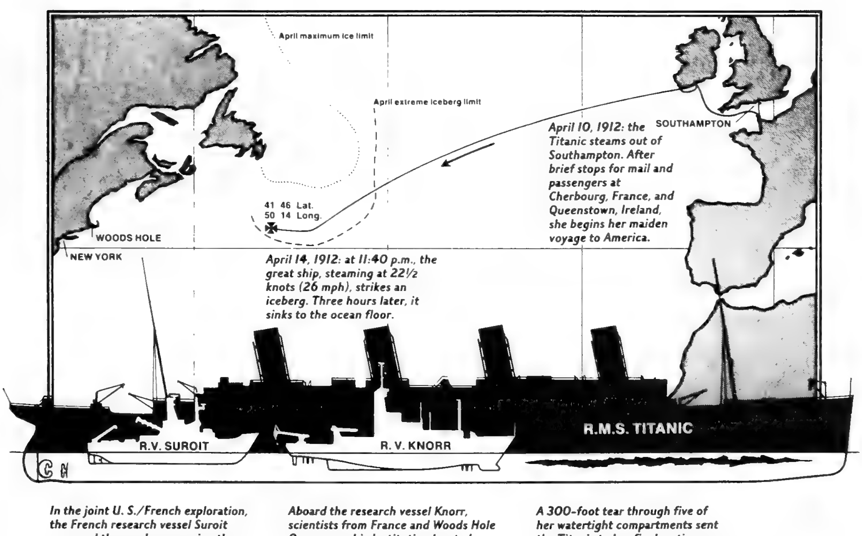

In the joint U. S./French exploration, the French research vessel Suroit prepared the way by narrowing the search area with sonar scanners.

Aboard the research vessel Knorr, scientists from France and Woods Hole Oceanographic Institution located and photographed the doomed liner.

A 300-foot tear through five of her watertight compartments sent the Titanic to her final resting place, more than 12,000 feet down.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 82–87, March 1986

Technology for Ocean Exploration

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Those afraid of the universe as it really is . . . and envision a Cosmos centered on human beings will prefer the fleeting comforts of superstition . . . But those with the courage to explore the weave and structure of the cosmos, even where it differs profoundly from their wishes and prejudices, will penetrate its deepest mysteries.

—*Carl Sagan, Cosmos*

What limits ocean exploration? For access beyond the edge of the sea and in depths greater than a few feet, the use of technology is necessary. But is the lack of appropriate technology the only reason that so little is presently known about earth's inner atmosphere?

I am going to pose a question to help put this issue in perspective. We are meeting now on a part of the earth called Florida. Would you describe this place as mountainous? High country or lowlands? Later we'll come back to this question and show its significance relative to the topic of ocean exploration.

Last spring I was among those who paid tribute at a meeting of the Explorers Club to a well known Arctic explorer who described his recent expedition, an arduous mountain-climbing feat, as "the last great exploration of the planet." I got the feeling that if I put up my hand and announced that I knew where there was a patch of ground ten feet square that no human eyes had ever seen before, I might be crushed in the rush of those who wanted to be the first there.

Perhaps a similar spirit motivated some of my fellow British countrymen who recently walked around the world, pole to pole, north to south and back. The reason they gave for doing it was that no one had done it that way before.

Such events do not bode well for those who would like to be explorers. Is it so that we humans have been everywhere, seen everything there is to see on the planet? To do something distinctively different, must one now hop backwards to the north pole? I like singlehanded sailing, but to achieve notoriety in this field, it might be necessary to travel around the world three or four times nonstop.

It is possible to walk or fly or take a jeep or boat or mule to any part of the planet at the bottom of the ocean of air that surrounds us, the apparent surface of the earth. Thus, there is a popular notion that the only frontier left is skyward, into the distant realms beyond earth's atmosphere. But what of that other, more dense atmosphere that mantles the planet—the ocean? Who has seen, let alone climbed the mountains that rest on the surface of the earth covered by water?

To overcome the problems of gaining

access subsea, several approaches may be used. One may freedive in the manner of whales and dolphins, by taking a deep breath and diving as deep and long as lung and muscle power will allow. Using scuba and saturation diving techniques, depth and time can be dramatically increased. For access to depths beyond a thousand feet, it is necessary to use a submarine, the underwater equivalent of an airplane, a self-contained protective system supplied with air maintained at one atmosphere.

In the past decade, the use of remotely operated systems and robotic devices has begun to complement the direct approach of "man-in-the-sea." Presently, more than 700 remotely operated vehicles ("ROVs") are in active use worldwide, mostly for military and commercial applications, but increasingly, for research and exploration as well. One of the most sophisticated of these is the *Argo,* operated by Woods Hole Oceanographic Institution and involved recently in the discovery and documentation of the sunken liner, *Titanic.* Presently, such systems are tethered, with a pilot guiding operations from a surface station. Autonomous, computer-driven systems are being designed that will be equipped with camera eyes and various sensory devices to gather information and react to circumstances encountered without moment-by-moment directions from a human being.

Half a century ago, the relative state of technology developed for access to the skies and to the seas was roughly equivalent. Aerospace technology has advanced enormously during the past half century, but among ocean engineers, it is still regarded as an event of some note to descend 3000 feet in a small submersible, although the first visit to such depths occurred in the early 1930's.

Much has been happening in the past decade, however. I shall recap some highlights of this era, concentrating on technology that I've been involved with, that coincidentally tells the story of recent advances and future directions.

The demands of the offshore oil and gas industry stimulated development of various new technologies, starting in the early 1970's. Saturation diving, originally a concept developed to prolong time subsea for scientific research and military applications, grew into a major industry. Oil rig operators paid more than $50,000 per day to keep a team of men ready to work in depths as great as 1000 feet, sometimes to 1500 feet, using exotic mixtures of compressed gas and complex life support equipment.

Various four to six passenger submersibles were also developed to work underwater and to transport divers under pressure from one site to another. Costs of operation—$20,000 to $50,000 per day—included a large support vessel capable of withstanding the rigorous offshore environment.

At the time I was an inexperienced engineer who aspired to design airplanes, but got involved instead working with torpedoes and diver propulsion systems for the Royal Navy. A small group of people became interested in reconfiguring the one man portable iron dress system, called *Jim,* to work on oil rigs, and engaged me for design work. *Jim* was originally developed in the early 1930's for salvaging the sunken vessel, *Lusitania.* After initial success, it remained idle until redesigned in the early 1970's. There are now 15 units working worldwide.

A man using *Jim* can go deeper than divers—2000 feet—and can perform work at a much lower cost. The system can only walk on a flat surface, however, and work subsea often requires moving vertically. Thus came the inspiration for a system that ultimately became known as *Wasp*—it's yellow and black and, like its insect namesake, it flies. Eighteen *Wasp* units are presently in operation, but in 1976, when I set about designing the first, the concept seemed revolutionary.

Work began not in a grand engineering design facility, crammed with computers and draftsmen and secretaries. Actually, there was no electricity in my office, a derelict cottage by the seaside near Nor-folk. The front door did not work, so I climbed in the window to get to my desk.

The place was quiet and peaceful, however, and within ten months of starting work, the first unit was ready to take to prospective customers. The cost of transporting *Wasp* from England to the Offshore Technology Conference in Houston was too great, so my colleagues and I took a large photograph and displayed it in a small booth among the giants of offshore industry.

Wasp created a minor sensation at its debut. Not only could it go twice as deep as most saturation divers—to 2000 feet it could also be operated for one tenth the cost. We thought everyone would like that. In fact, nobody did. The diving companies were quite happy charging $50,000 a day and did not much like the idea of getting only $5000 for *Wasp*. They did not want to buy it, but neither did they want their competitors to have it. Within a few weeks, we were avidly courted by several large companies. This was very flattering at first. Then it became clear that they all wanted to buy that one machine and get exclusive rights to ensure that no more would be built. At that point, things began to get nasty. An American company sued us and a British one took the more straightforward approach and simply stole the only *Wasp* then in existence. The matter was happily resolved in the end, with the American company buying four full years of production. After two years, the original *Wasp* was recovered and sold at a nice profit.

I tell this story only to emphasize that not everybody welcomes technological advances that enhance working capability and also greatly reduce costs. We got through difficult times with *Wasp* largely because of our naivete and the sheer blazing conviction that is borne of righteous indignation.

Since all production of *Wasp* was locked up for several years, it was time to design something new. I set to work on another kind of one-man system, *Mantis,* launched in 1978. *Mantis* is quite different from the anthropomorphic *Jim* and *Wasp*. They, like astronaut's suits, have articulated limbs operated by muscle power. The operator actually has his arms in metal sleeves. The operator of *Mantis* uses metal and plastic manipulators controlled from within the cylindrical pressure hull. The system is propelled by strategically positioned thrusters controlled by a push-button panel provided with arrows indicating directions.

Thirty *Mantis* systems have been produced and are employed throughout the world in support of the offshore oil and gas industry. *Mantis* is successful because it is small, easily transported and deployed, and there is working capability normally possible only in much larger, more costly submersibles. At the time *Mantis* was introduced, about twenty large submersibles were being operated from ships in the North Sea. They soon became commercially extinct because *Jim, Wasp, Mantis* and a growing fleet of ROV's could do the work required at a fraction of the cost of operating the large systems.

Except for a few large submersibles working primarily for science, this type of submersible has become obsolete. Among those that continue to perform sterling service for science are the Harbor Branch Foundation's Johnson-Sea-Link systems and Woods Hole Oceanographic Institution's *Alvin*.

Let's go back now to the questions raised at the beginning. Are we sitting here on a mountain, or is this a lowland? Is technology the limiting factor preventing us from gaining access to the sea, or is something else holding us back?

Taking the astronaut's view of the earth, it is obvious that the oceans dominate the planet. Taking the narrow perspective of earth-bound human beings, there is an impression that land dominates. It wasn't so long ago that the popular concept of the earth was that it is flat, bounded by corners, with a canopy of sky overhead. Proof that earth is round was disquieting to many, but acceptable as long as humans remained the center of the action. People who insisted that we must be the pivotal point of the universe had a difficult time accepting the premise that the earth moves around the sun rather than visa versa.

Many still have a problem imagining that the earth may not have been designed just for our pleasure, but most seem to have adjusted to an understanding of where earth is relative to the cosmos—a small blue planet associated with a minor star in one of many galaxies.

A typical map of the earth showing continents and islands surrounded by a featureless ocean reflects our self-centered terrestrial bias. If we were to put the same question about Florida to some savvy dolphins and whales, the answer might be different from the response given by most people. From the standpoint of sea creatures, Florida's base is several thousand feet from its top, and seven miles from the ocean's deepest location. Doesn't it make sense to measure the height of a mountain from its bottom, rather than from the interface where the air atmosphere meets the water atmosphere? Looking at it this way, Florida is a mountain with a rather level top, but a mountain nonetheless. "Sea level" as a baseline reflects our landbound point of view.

Taking the deepest part of the ocean, the Challenger Deep in the Mariana Trench near the Philippines, as the reference point, we are presently standing on a mountain more than half the height of Mount Everest. We are 37,000+ feet from the deep ocean reference point, and Everest stands approximately 62,000 feet above the same point.

From the perspective of a dolphin or whale, we humans are poor terrestrial beings huddled together on that bit of land that projects through the ocean, through the inner atmosphere that is home for most of the life on earth. We are literally imprisoned on the top one third of the planet.

The man honored last year by the Explorer's Club had it wrong when he said that the era of exploration is over. In fact, it is just beginning. We have trampled on

Fig. 1.

the top one third of the planet, but the majority of the earth's surface that is covered by water has never been reached, even by ROVs, or nets or instruments, let alone by humans who are determined to see and experience for themselves.

Suppose it is acknowledged that, indeed, we don't know as much as we thought, and that ocean exploration is something that must be undertaken in a major way. Is it technologically feasible? Could we, if we wanted to, explore the base of this Florida mountain, or are there major problems yet to be solved?

Before answering, I would like to describe a vision, a dream that began several years ago as a result of discussions with the chairman of this session concerning how to get to the bottom of the ocean—and return. It is a dream shared with and in part supported by the Charles A. Lindbergh Fund through a grant in 1981. Imagine being able to step into the ocean of your choice and glide into the depths without being concerned about getting cold or running out of air. Imagine a comfortable seat within a transparent pressure hull and two sensory manipulators that respond to controls that are operated instinctively. Imagine a vehicle called *Deep Rover* that is not make-believe, but real. The first of what I hope will be many was launched in the summer of 1984.

Deep Rover (Figure 1) is sophisticated, but simple to operate. Evidence of how simple it is to operate was achieved one Saturday when fifteen people, including my 13 year old son, Jonathan, were each given 20 to 30 minutes of instruction before they became pilots in command of a free-swimming submersible. They found that slight forward motion on the arm rest engages appropriate thrusters and the sub moves forward; reverse is triggered by leaning back. Such movements soon become instinctive and most of the pilot's attention can therefore be concentrated on what he is there to do.

The dream, now closer to reality than when we first started talking about it in 1979, is to dive pairs or teams of *Deep Rovers* and, by using ceramic glass rather than acrylic for the clear pressure sphere, to make descents to seven miles a routine occurrence.

In conclusion, whatever one wants to do in the oceans, can be done, technologically. Put a budget of, say, $100 million or perhaps even $10 million, a fraction of what is spent by this nation on hundreds of matters of no greater importance than this. Allow two or three years, and there is virtually no limit to where it will be possible to go in the ocean.

Do you want to go to the deepest part of the sea? It was done 26 years ago by Don Walsh and Jacques Piccard and surely could be done again if we decide to do so. Technologically, solutions to problems relating to great pressure and other challenges already are in hand. It is noteworthy that no nation, including the U.S., the U.S.S.R., Japan, and France, presently has the capability to go deeper than about 20,000 feet in a manned system. The last vehicle in the Trieste series used by Walsh and Piccard was decommissioned by the U.S. Navy in 1984.

Technology generally has made rapid advances in the past few decades, the last in particular. Little of this is presently being directed toward the ocean, but the materials are there, the technology is waiting to be used.

What do you want to do? Do you want to build cities underwater? We can do that. Do you want a subsea restaurant? We can do that. Do you want to take you aunt and your grandmother down in a tour sub to see coral reefs and visit with dolphins on their own terms? This is underway right now. What do you want to do in the sea? It can be done. The limitations are not technological, they are psychological and self-imposed.

If the citizens of this great country, America, ever got it in their heads that they were in prison, unable to move at will throughout the planet, there would be a clamor to break free, to remove the barriers, and to commit to a vigorous program of ocean exploration.

Presently, the oceans are ignored, just as the ancients ignored and turned away from the unknown hazards beyond the horizon. It was more conforting, for a while, to imagine that monsters were waiting just over the edge of the flat earth, so best stay away. But, just as a few in ancient times risked the monsters and gained priceless new understanding of the world, so must risks be taken again. What, other than ignorance, is there to lose?

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 87–88, March 1986

The Living Seas

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More than 10 years of design and construction have gone into Walt Disney World's newest EPCOT Center pavilion, The Living Seas. Dedicated to the exploration of human-kind's relationship with the ocean, The Living Seas was designed from start to finish to provide an intensely entertaining and educational forum for the presentation of ocean related sciences.

Twenty-seven feet deep and 203 feet in diameter, the man-made salt water environment has a life support system which recirculates and filters all 5.7 million gallons within 3 hours to maintain a naturalistic eco-system for the sealife of the coral reef.

Rockwork at the entrance recreates the organic forms of a natural coastline, with waves cascading into tidepools. A curving wall with a 125-foot-long, stylized ocean mural draws us inside, where we pass through a showcase of man's historical fascination with undersea exploration.

Reproductions of Leonardo da Vinci's sketches of underwater breathing devices and submersibles, John Lethbridge's diving barrel and Frederic de Drieberg's 1809 breathing device are a few of the curiosities displayed here. The dive suit from the classic Disney film, "Twenty Thousand Leagues Under the Sea," and the actual 11-foot-long Nautilus model are also showcased.

A formal welcome is extended by United Technologies, the pavilion's participant, in a 2½-minute special effect multi-media presentation introducing the pioneers of modern ocean exploration. A high-technology company with worldwide headquarters in Hartford, Connecticut, United Technologies employs some 194,000 people. Among some of their best-known products are Pratt & Whitney jet engines, Carrier air conditioners, Sikorsky helicopters and Otis elevators and escalators. Examples of United Technologies' interest in ocean exploration and the highly specialized equipment supporting these ventures are seen throughout The Living Seas.

The ocean's mysterious depths and its effect on our lives are the subjects of a 7-minute show which combines 35 mm live-action film and computer animation to focus on the ocean's inextricable link to our survival.

After the show, theater doors open to

reveal elevator-like capsules called "Hydrolators," which take us on a simulated plunge to the ocean floor. We arrive at Seabase Alpha, a prototype "21st century" undersea research and visitor center.

Boarding two-passenger "seacabs," we embark upon a 3-minute voyage that takes us through an underwater world, populated by sea creatures, divers and robotic submersibles darting among the coral, rockwork, and plantlife of a Caribbean coral reef environment. As our vehicles move through tunnels with acrylic viewports 25 feet below the water's surface, we look upon schools of tropical fish, sharks and other real ocean inhabitants within their naturalistic eco-system. Some 200 varieties of sealife swim around us, including sharks and rays, sea bass, puffers, barracuda, butterflyfish and angelfish.

Within this environment, the diver crew of Seabase Alpha is testing new diving systems. The crew also conducts experiments in dolphin communication and monitors the chemistry and biology of the ocean environment.

The Visitor Center of Seabase Alpha showcases current and future ocean technology in demonstrations, exhibits and interactive shows. These exhibits are housed within six modules, each dedicated to a scientific topic crucial to our exploration and understanding of the sea.

Seabase Alpha has been designed so that it will be able to keep pace with the leading edge of scientific thought, through the use of varied presentation mechanisms such as: large screen video presentations, interactive video-disk systems and the most versatile educational tool(s) of all; the Seabase's scientific staff who interact with the guests as members of the "crew." These crew members who will be functioning on and off-stage, will also be taking in ongoing research programs which, like The Living Seas itself, are just beginning to evolve.

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 89–93, March 1986

Research and Development of Ocean Resources

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ABSTRACT

Oceanography, the science of the sea, is the crucial first step in efficient development of marine resources. To know what is there, learn its concentration, study the formative processes, understand life cycles and develop the ability to predict location/occurrence are all vital factors whether the potential resource is living, non-living, or a use of ocean space. Simply having scientific information is not enough. There are three additional steps before effective commercial development can be attained. These are: develop the technology to build machines to work in the sea, undertake an economic evaluation of a proposed resource development and develop supportive public policy. While scientific, technological and economic analysis methodologies are fairly well understood, the policy area often produces the most difficulties and delays. Therefore "research and development" activities for development of ocean resources must embrace all four areas to insure a balanced approach to uses of ocean space.

Ocean Space: A Large Area for a Small Paper

Clearly it is not possible to fully describe here the full path of ocean resource development from the initiation of basic research, at the beginning, to commercial resource production at the end. However it is possible to give an overall concept of how events, or developmental steps, must be sequenced to insure a balanced, efficient approach to use of this vast region.

It might be helpful at this point to 'calibrate' the reader with what is meant by "vast region". The world ocean covers 71% of our planet; its average depth is about two miles, and the maximum depth is seven miles. The volume of the oceans is about 360 million cubic miles, a number so large that it loses meaning. However noting that all of the world's population could be put into one cubic mile of seawater gives some scale to this number.

In economic terms all of the U.S. ocean-related business contributes over $100 billion dollars a year to our gross national product. And there are 138 other coastal nations in the world. Therefore this brief paper, of about 3000 words, can be prorated at about $33 million per word just for the value of the U.S. ocean industry.

The Uses of Ocean Space: In Four Steps

The path from basic research to commercial venture involves four broad steps:

• **Science: What's There?**
The study of the oceans in terms of their physical, chemical, biological and geological properties.

• **Technology: How Do We Get It?**
The adaption of technologies to our knowledge of the oceans to produce machines to work in and on the sea. This includes machines science to study the sea.

• **Economics: Is It Worth Doing?**
Solving scientific and technological questions does not guarantee efficient uses of the sea. Economic analysis determines whether or not a proposed resource development program can produce a profit for its operator.

• **Public Policy: Politics Has the Last Word.**
This last step involves the 'man-made' constraints on uses of the sea. Government policy determines under what conditions resource development will take place. Public interest groups attempt to influence government policies to insure that resource development is undertaken with full consideration given to effect on the environment and to finding balance between alternative uses. Cultural questions also influence policy when traditional ways of life are affected by a resource development (or non-development). In many ways the whole area of public policy provides the greatest number of difficulties for the development of ocean space. Science, technology and economics can be reduced to fairly specific scientific methodologies and analysis. Human factors used in the development of intelligent government policies are far more complex.

Oceanography: The Provider of Information

Oceanography is not very old compared to the fields of pure science such as physics, chemistry, mathematics and geology. In fact, oceanography is not even a pure field of science. It is interdisciplinary, essentially embracing most existing fields of science and applying them to the marine environment. An oceanographer generally belongs to one of four major disciplinary categories: biological, geological, chemical and physical. The first three categories are pretty self-explanatory. The fourth, physical oceanography, can be simply described as the study of the motions of the ocean and its interaction with its air and land boundaries.

Oceanography: The Early Days

Inquiring men have looked at and studied the sea for literally thousands of years but there was little formal organization and analysis of what was observed. Resources, (uses of the sea) did not depend upon or use this information to any large extent.

In the 1840's a U.S. naval officer, Lieutenant Matthew Fontaine Maury undertook a project to organize, analyze and chart voluntary observational data taken by naval, whaling and merchant ship captains. Maury knew that a great mass of information could be available from the hundreds of ships that covered large ocean areas. If this information could be organized by season and region certain useful patterns might evolve that could assist all mariners to be more successful. The result of this work was two publications which revolutionized maritime safety and efficiency, "Wind and Current Charts" and "Sailing Directions". His book, "The Physical Geography of the Sea" (1855) is credited with being the first modern oceanography textbook. Maury's diplomacy, hard work and careful studies earned him the unofficial title, "the first physical oceanographer".

Oceanography's formal beginning as an interdisciplinary science was about 110 years ago, when the British Challenger Expedition (1872–76) left England on an around-the-world scientific voyage. About this same time (1873) the first marine laboratory was established at Naples, Italy. By the turn of the century, oceanographic studies were being conducted in many places throughout the world.

Marine biology relating to fisheries was the primary thrust of most marine research prior to the beginning of World War I. Prior to that time no marine minerals were taken from the sea and the study of ocean currents and water depths were mostly confined to improving safe navigation of ships in coastal waters. However the tragic loss of the steamship TITANIC in 1912 did set in motion studies of icebergs, their formation and drift trajectories. In fact, these studies continue to the present.

The war helped stimulate the need to have more information about the oceans, especially in learning how to detect and destroy enemy submarines. Since the primary means of detection was sound propagation through the water, the field of marine acoustics was born.

World War II research efforts expanded upon this work and by the end of the war effective active and passive sonar (sound navigation and ranging) systems were installed on both submarines and surface ships. Both the knowledge of the marine environment and matching technology now set the stage for a major expansion in the field of oceanography.

Predictive Information: Key to Effective Uses of the Sea

The product of marine scientific research is predictive information. That is, information that can be applied to uses of the sea. Following the scientific method the scientist observes, hypothesizes, and experiments. Finally he develops, and then tests a predictive model for the phenomenon being observed.

Once we can understand and predict marine phenomena, whether they relate to marine weather or to the abundance of fish in a certain area then we can use this information for the benefit of commerce.

Not all "predictive information" finds an immediate application in the commercial marketplace. Actually very little makes it this far. Thus the term "resources" has a specific meaning. It refers to those materials, properties and space whose availability, predictability and value make them economically important if they were to be exploited. To pass the test of being a resource the key determinant is the economic one. Thus while many things of potential value are found in the world's oceans only a few command commecial value. The balance remain scientific curiosities, helping scientists to understand more about the sea but not achieving the status of resource. Of course the situation is not static, new knowledge and new technologies frequently convert yesterday's curiosity into tomorrow's resource.

The Resources of the Sea: A Quick Sampling

In considering marine resources we can divide them into three broad categories: living, non-living and oceanspace use. The common thread in all of these categories is the essential need for predictive information in order to be able to conduct effective and economically viable operations on and under the sea.

Living resources means all living things, animals and plants, in the sea and on the seafloor. Other than marine transportation/exploration this is the oldest resource use of the ocean. While only about 15% of the protein needs of the world's population is supplied from the sea, there are promising new developments that may increase this supply. The most obvious is to know more about the oceans as a means to better harvest available fish stocks. New technologies such as ocean sensing satellites are providing this capability.

The new field of bioengineering will permit improvement of natural fish stocks as well as greatly improve the efficiency and yields of fish farming (aquaculture) operations. At present about 10% of the fish consumed in the world comes from aquaculture; this figure could be greatly increased through the application of bio-engineering.

Marine organisms (plants and animals) have greater levels of bioactivity than do terrestrial organisms. Of particular interest are bioactive compounds that can be derived from living marine resources which can be the basis for new generations of pharmaceuticals.

Non-living resources are generally the hard minerals and liquid/gaseous hydrocarbons taken from the subseafloor, seafloor, and from seawater itself. In addition this category includes renewable ocean energy such as ocean thermal difference, waves and tides.

While not economically feasible at present, it is clear that mining of ocean mineral deposits will be an important source of raw materials early in the next century. The technology is in hand and has been tested; it's only a matter of time until market demand catches up with capability.

Oil and gas from the seafloor also is an area where a depressed world market for hydrocarbons has been reflected in offshore development. But the demographics of the world population tell us that this is only a transient 'energy glut'. Most of the world's new discoveries of hydrocarbons will come from beneath the seafloor. Ocean thermal energy which is renewable and non-polluting will become more attractive as the per barrel price of crude oil increases in the future. Again, the technology is in hand and has been tested.

Finally, oceanspace use embraces the ocean as a place for certain activities such as transportation of the world's commerce; waste disposal, and marine recreation.

Approximately 99% of world trade (by tonnage) travels by ships between nations. This percentage will remain constant although total tonnage will increase as third world economies develop and expand. New technologies such as automated ships and super ships will greatly reduce operating costs while improving maritime safety.

Man will continue to generate wastes and as populations increase so will this 'byproduct' of numbers of people and increasing affluence. The oceans must be considered as one of the acceptable sites for disposal. To safely do this, we must know more about ocean processes.

The developed nations create leisure time and disposal income for their citizens. This translates to increased recreational activities, especially in the marine area. In the U.S. marine recreation contributes more than $28 billion a year to the gross national product. This is a major growth area for ocean industry.

At present ocean industry is depressed in many areas. Oil and gas are too abundant and prices per barrel of crude have fallen dramatically. The 'oil glut' has cascaded throughout the marine industry and related sectors such as offshore drilling services, shipbuilding and tanker operations have all suffered. World shipping has too much capacity for the amount of cargoes available. This is not only in the tanker trades but also in general cargo shipping. Understandably the world shipbuilding industry is badly depressed due to poor offshore oil and gas prospects and the overcapacity in cargo shipping. Finally worldwide fishing activity seems to have reached a plateau of about 70 million tons a year and there has been little change for several years.

But the news is not all bad. Marine recreation is a major growth area. Port and harbor operations still expand and are profitable for most major seaports. And as always, national investments in navies seem to continue to increase.

This mixture of good news/bad news must be understood as a transient situation. One only has to look at forecasts for world demand for energy, minerals and marine protein to understand that there will be a return to demand. The hard part is attempting to calculate when this will happen in each of the resource areas.

In areas such as oil and gas, and ocean mining the lead times for resource development are in the order of 10–15 years. Therefore it is not unreasonable to suggest that doing the relevant oceanographic research now will provide the knowledge needed to develop the resource in the future when economic conditions are better. In other words there can never be a worldwide 'glut' in marine scientific information.

Summary: Reality Versus Hope

The distance between basic scientific investgation and actual commercial practice is great, sometimes too great. As noted earlier, at every step of the way there are major problems which need to be addressed to insure that the people of our planet can enjoy maximum use of the resources of ocean space. As Marshall McLuhan said, "There are no passengers on Spaceship Earth, we are all crew". A primary problem is lack of public investment in marine science and technology. Because such activity produces results over the long term (10–20 years) it is hard for governments, which are short term (4–8 years), to be concerned about problems relatively so far in the future. But without the fundamental predictive information, and matching technological capability, the result will be greatly restricted resource uses of the oceans.

In the United States our national budget allocations for marine research and technology have just barely kept up with the inflation rate over the past decade. The U.S. is not alone, a similar situation is found in other major maritime nations. Yet we know that only a small fraction of ocean space has been explored for its resource wealth while an expanding world population continues to put a strain on existing terrestrial resources.

Resource development without the supporting foundations of science and technology is wasteful, economically inefficient and potentially harmful to the ocean environment. Yet this may be the case if proper support is not given to doing the needed fundamental research in the oceans. This is not an argument for massive government support for marine science and technology. The role of government in this area is to fund *basic* research where there is high risk, the national interest is involved and where the rewards are some years in the future. A government partnership with the entrepreneur will permit a smooth transition from basic research to commercial practice with each player undertaking the role that he is best suited to fill.

There is still time to do it right. However there must be much greater public involvement to insure government policies encourage more extensive studies of ocean space and that government budgets provide the needed resources. This public awareness can only come from education and information activities which actively lobby the public to become more concerned with the care and use of "spaceship earth".

Journal of the Washington Academy of Sciences,
Volume 76, Number 1, Pages 94–96, March 1986

A Synthesis of Presentations

Surgeon Vice Admiral Sir John Rawlins

Chairman of the Board, Deep Ocean Engineering, Inc.

The philosophy of the Charles A. Lindbergh Fund reflects that of the man for whom the fund is named. That philosophy is that a balance must be struck between technology and the environment. This is what Lindbergh called, "the wisdom of wildness."

I see a parallel in this and in a sport that I particularly enjoy—judo. Judo is the science of balance. The philosophy of the Greek athletes was, "a healthy mind in a healthy body." The presumption is that by educating your body to a healthy state, that you thereby would develop a healthy mind. In judo, the objective is to have a balanced mind in a balanced body. Judo depends upon maintaining your own balance, disturbing your opponent's balance, and in preventing him from regaining it, thereby bringing about his downfall. Good health and good balance are interdependent. I do not think that it is necessary to draw obvious parallels with the state of the planet.

A number of important themes have emerged from this conference, some that have become apparent only after reflecting on the whole, having heretofore concentrated on the individual components. Some highlights follow:

—Satellite imaging, vital to maintaining an overview of the state of the planet, needs further development, support, and application.

—Communication of the conservation ethic via entertaining but instructive films, museums, aquaria, zoos and centers such as Epcot's Living Seas Pavilion, was repeatedly endorsed.

—Development of replenishable energy sources such as solar and wind power and the use of hydrogen must be encouraged.

—The need to stem the loss of species diversity and the use of diversity as a yardstick to gauge a healthy vs. an unhealthy environment was a recurrent topic.

—The loss of species may be on the order of 10,000 per year through the destruction of rainforests and other critical habitats, while replacement by newly evolving forms may be only on the order of one per year. Protection for critical habitats and captive breeding programs for rare and endangered species coupled with broad public education concerning the tragic consequences of the loss of species were discussed as some of the ways to address this imbalance.

—The need to solve problems relating to toxic waste disposal is of critical importance. Methods for doing so involve legislation and regulation, but these in turn often generate new problems such as stifling innovation and increasing costs.

—Recently developed methods make it

possible to detect traces of certain toxic substances to and within a quadrillionth of a percentage. Such sensitivity increases capability concerning understanding and dealing with toxic materials, but can be troublesome as people attempt to grasp the significance of such small amounts.

—A repeated underlying message concerning waste disposal was, "There is no away, anymore." We must face up to the problems of generating and disposing wastes or face the regrettable consequences.

—The perception that exploration of the planet is essentially complete was shown to be nonsense, in part by evidence that most of the planet is ocean, and most of the ocean has not yet been explored either directly by humans or by remotely deployed machines. It was also pointed out that only five or perhaps fifteen per cent of all the species of organisms presently living on the planet have been described scientificially. This suggests that much exploration remains to be done.

—It is clear that the responsibility for maintaining a healthy planet rests largely now with the actions of mankind.

—It is both ecologically and economically sound to use ecosystems in a sustainable way.

—The theme that "time is our most precious resource" came with a corollary: "We need to take advantage of technology in order to ensure its most efficient utilization."

—Increasingly, the resolution of environmental matters involves law and public policy, often to positive ends, but sometimes with costly and confusing results.

—Some have suggested protection for remote environments, such as the deep sea, and remote sites of historic significance, such as the sunken passenger liner, *Titanic,* can be achieved by maintaining a cloak of ignorance. The rationale is that it is more difficult to damage or destroy something that can't be found or reached. This suggestion was countered by the theme, "with knowing comes caring." Many historic sites and priceless natural areas have been destroyed deliberately or inadvertently because their value was not appreciated. Education, not ignorance, is needed to gain lasting protection.

—It was noted that the earth, seas, sky, and space beyond are as pristine now as they ever will be, if present trends continue. There are opportunities to learn from wildness and set standards for all that follows. This is particularly apparent concerning understanding the balance that comes about in natural ecosystems, but there are other specific examples of the "wisdom of wildness." One example is that it takes the very latest aerospace techniques to crudely approximate what nature achieves with ease concerning flight among insects, bats, birds, and even ancient reptiles.

Concluding thoughts were provided by Reeve Lindbergh Brown. She said her father, of course, could not have known twelve years after his death, on the anniversary of his birth, that a group of people would be meeting to address a topic which was the focus of much of his life—balance. He would be pleased, she thought, to know that individuals were actually taking responsibility for achieving and maintaining the balance he believed to be vital to survival.

She recalled an observation I made that a tragedy can be measured by the size of the audience, by the number of people affected. Triumphs, she said, can also be so measured.

In her father's lifetime, personal triumphs and tragedies both involved sizeable audiences. His concerns for achieving a balance have belatedly been shared by an increasingly wide audience, including those gathered for this symposium, and those who will read the printed results.

Noting that one of the panels concerned "outer space" and "inner space," she made reference to thoughts that her father jotted down on a pad just before one of her last visits with him. He had mused, "I know there is an infinity outside of us; I wonder if there is also an infinity within."

This conference has not only expressed the philosophy of Charles Lindbergh; it has also found his spirit.

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VOLUME 76
Number 2
June, 1986

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly
at Washington, D.C.

EDUCATION: THE SPIRIT OF THE AMERICAN MUSEUM

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Washington Academy of Sciences

Founded in 1898

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This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Executive Committee; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the December issue contains a directory of the Academy membership.

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Published quarterly in March, June, September, and December of each year by the Washington Academy of Sciences, 1101 N. Highland St., Arlington, Va. 22201. Second class postage paid at Arlington, Va. and additional mailing offices.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages i–iv, June 1986

Editors' Introduction

Museums are customarily regarded as repositories for the natural and cultural record. But the passive connotation of "respository" is not borne out by actual museum practice. Through what they choose to collect as well as how they decide to arrange collections, museums implicitly express which conceptions of art, history, or science are worthy of attention. But the state of scholarship in museum-related disciplines and attitudes about the public underlie the constant process of decision-making that pervades museum practice and inevitably informs museum performance.

The modern museum has been described by J. Mordaunt Crook in *The British Museum* as a "product of Renaissance humanism, eighteenth-century enlightment, and nineteenth-century democracy." Admirers of antique pedigrees prefer to harken back to the Mouseion of Alexandria, a center for learning that flourished from the third century BC to the third century AD, as a conceptual antecedent to today's "seat of the muses."

Yet this seemingly mixed ancestory is not without a common thread. A degree of genuine continuity can be discerned in museums' gradual progression from the sixteenth-century *Wunderkammer*, an amazing place where the privileged few viewed an eclectic collection of natural and manmade objects, to twentieth-century discovery rooms where visitors are invited to attend participatory exhibits with collections of artifacts specially selected for "hands-on" learning. Certainly, in America the amassing and display of collections have generally been associated with popular access and education. Consider Charles Willson Peale's wondrous—and profitable—museum that brought together, for the edification of visitors to Independence Hall in the late eighteenth and early nineteenth centuries, portrait paintings of the heroes of the Revolution, preserved specimens of wildlife in naturalistic habitats, a fully-mounted skeleton of a mammoth, an illusionistic painting of his sons ostensibly pausing on a staircase, and the like. Or the Boston Museum of Fine Arts, founded in 1870 by civic-minded individuals with the express intent of "collecting materials for the education of a nation in art, not for making collections of objects of art." And there is the Memphis Pink Palace Museum and Planetarium established around 1930 with the strict stipulation that "every exhibit must teach something."

Just recently, the American Association of Museums' Commission on Museums for a New Century published a report that calls upon museums to rededicate themselves to their historic mission as agents of popular education. The report recommends that museums embrace the concept of the centrality of learning and states, "If collections are the heart of museums, what we have come to call education—the commitment to presenting objects and ideas in an informative and stimulating way—is the spirit." The commission was firm on this point: "The American museum does not simply exhibit," they reminded their colleagues, "it teaches as well."

Today, the museum community is seriously examining its role as an educational institution—wondering about its responsibility to its audiences, questioning its strategies for public awareness, and examining its methods of teaching through the use of collections of objects. In this journal issue we invite readers behind the scenes of the museum. This excursion is intended to allow you to eavesdrop on professional conversations going on in the museum world. The papers presented here focus on some current thoughts and events shaping the developing field of museum education. This is a period of self examination for museums and education. Museums are reexamining their definitions of education and learning. Staff are no longer satisfied with recitations of attendance figures as the chief indicator of their educational success. Museums are increasingly interested in the quality of a visitor's experience. And while school children will always be an important audience, many museums are currently extending their educational efforts to include consideration of the adult, casual visitor. In 1986, museums are broadening the base of their educational mission.

Educational responsibility is firmly embedded in the philosophical foundation of American museums, but as you will discover in the assembled collection of papers, museum professionals are still searching for a clear understanding of how people can learn best in the museum environment. Museums have yet to realize their full potential as educational institutions, and promising initiatives are emerging in all parts of the country. Regional study groups are exploring theoretical foundations for museum education. The J. Paul Getty Trust commissioned a study of education departments in several large art museums and is spearheading a movement toward the articulation of philosophical foundations for museum education. In recognition of the central role of education, many museums have undergone internal reorganization. Education concerns are becoming central to museum operations as heads of education departments become assistant directors of museums and as educators join curators and designers on exhibit design teams.

The collection of papers presented in this issue offer several perspectives on museum education. Here museum professionals reflect on their work and on their responsibility to their audiences. Danielle Rice, Curator of education, Philadelphia Museum of Art, argues that learning from objects of art is not limited to absorbing information about them. She worries about visitors' dependency on labels and docent talks, and she hopes that visitors will question, analyze and think critically as they look at art. She wonders, "Can the museum teach people the critical thinking skills needed to unlock the mysteries of art?" Such skills, she contends, are the key to making viewing art a personally meaningful experience.

Linking artifacts from the past to people living today is also the concern of Fath Ruffins, an historian at the National Museum of American History (NMAH). Ms. Ruffins recently directed the reinstallation of a portion of the museum's permanent collection. She discusses the process of developing the exhibit, "After the Revolution: Everyday Life in 18th Century America." The exhibit is the NMAH's first attempt to present a social history interpretation of American life. History, Ms. Ruffins asserts, is more than specific dates and other facts. And for the museum, the presentation of history involves more than the display of artifacts and the story they tell. Ideas, points of view, and changing interpretations guide the selection and placement of objects. Thus, visitors should be aware of the choices that have been made and should approach an exhibit asking, "What is the museum trying to say?"

Parker Potter and Mark Leone suggest that museums do not pay enough attention to the messages they present through their exhibits and programs. Five years of innovative work in Historic Annapolis brings these authors to the conclusion that museums need to give more attention to what they teach—looking for the several layers of meaning inherent in any museum presentation. They discuss their own work in Annapolis. It serves as a model of the use of ethnographic research in the development of a theme for a museum program. Potter and Leone insist that it is the responsibility of the museum to teach the public about the methods of history rather than leave people with the false impression that there is one, right view of historical events.

The issue also includes reports on several recent and important developments in museums—science and technology centers, participatory exhibits, and a project designed to rectify gaps in museum research and exhibition programs. Finally, Harris Shettel discusses the ways museums evaluate the educational effectiveness of exhibits and programs.

The museum professionals represented here are engaged in questioning the authority and effect of their own voices through the exhibitions they mount and the programs they present. At the same time, they have advice for museum visitors. Today, public attention is drawn especially to large exhibitions as they become the mainstay of our largest and best museums. Public perception of museums is shaped by exposure to blockbuster exhibitions such as "Aditi: A Celebration of Life," "Louis XIV: The Sun King," and the more recent Renoir retrospective in Boston and "Treasure Houses of Britian" at the National Gallery of Art. Though these captivating events are an important part of the modern museum world, they offer a limited view of a museum and its vast collection. The dazzling presence of these wonderful exhibitions all but blinds visitors to the treasures found in the museum's permanent collection.

The authors of this volume invite readers to look at museums more carefully, to ask questions, and to become even more thoughtful museum users. A prominent museum professional, Edgar Preston Richardson, addressed the issue of the underuse of museums on the occasion of his acceptance of the museum community's most prestigious award, the American Association of Museum's distinguished service award. Mr. Richardson observed that, "What is missing from the museum world of North America is an educated adult comprehension of the immense and fascinating treasures of art, science and history assembled in our museums. Adults," he points out, "remain unaware of the importance of what is in the collections of the museums of the United States and Canada. Lying unseen and unknown in the prominent collections of the museums of North America are things so important, so interesting, so rare and valuable—things that tell the story of the earth and of life upon earth—that they form an enormous resource of knowledge and pleasure to those who will give them thought and attention."

With this issue we commend museums to your thought and attention. Museum collections are a vast untapped resource. This issue of the *Journal of the Washington Academy of Sciences* is dedicated to informing a special, interested audience of new ways to use the museum—ways to enrich your research activities and personal learning. It has been said that museums represent, with libraries, the two halves of the public memory. Museum staff members acknowledge that this "memory" seems to be as much about the present as it is about the past. We go to museums, it seems, hoping to see the beautiful, the old, and the informative. But what we actually see in the museum is ourselves.

Carol B. Stapp
Mary Ellen Munley

Acknowledgements

We would like to acknowledge the generous assistance provided by Anne-Louise Marquis, Tracey A. Eberle, and Ann Grogg in the production of this issue. We are also grateful to the *Journal of the Washington Academy of Sciences* for offering this impressive forum to museum professionals for "talking shop" and to Marcella Brenner for her skillful matchmaking that led from a single article to an entire issue dedicated to learning in the museum.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 97–105, June 1986

Liberation Not Replication: "Archaeology in Annapolis" Analyzed

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Educational excellence in history museums rests upon thoughtful and thorough consideration of three fundamental questions:

Why teach?
What to teach?
How to teach?

But how to teach has been much more extensively discussed in history museums than what to teach, while why teach has gone virtually unasked. Perhaps the assumption—largely unchallenged since Aristotle's *Aesthetics*—that objects communicate directly through sight or touch underlies slighting the issue of *how* to teach in history museum settings. And assuming that objects themselves teach (rather than the exhibit designer who arranges the objects, or the curator who writes the labels, or the museum educator who develops the programs) relieves responsibility for deciding *what* to teach in history museums. Further, the American faith in education as an unqualified good no doubt circumvents questioning what education is good for in the history museum—in other words, *why* teach.

Although these three central questions may not be considered explicitly by museum staff, every museum exhibit and program is nonetheless based on implicit answers to why teach, what to teach, and how to teach. Moreover, these questions—and their answers—are inextricably intertwined: how to teach is determined by what is being taught; what is being taught is determined by why the teaching is taking place.

The public program of "Archaeology in Annapolis" evolved from explicit consideration of these three key questions. This four-year-old experiment in outdoor history education is part of a year-round exploration of the archaeological record of eighteenth-century Annapolis. Initiated by Historic Annapolis, Inc. (a private, research-oriented preservation organization founded in 1952) in conjunction with the University of Maryland, the project seeks to contribute to understanding the commercial base of the port city, its property and wealth structure, and relationships among the groups who inhabited the city.[1] To date a dozen sites have been excavated or tested; six have been opened to visitors.[2] The public program is intended to make the techniques, methods and findings of archaeological research in Annapolis available to residents and tourists alike.

Why We teach

It has been argued persuasively that nineteenth-century American school texts were written to stabilize society, to maintain the status quo, to replicate rather than to liberate.[3] Education that fosters replication—teaching people what they already know or new information just like what they already know, operating through the emotions or senses—is the outcome of failing to ask why teach. Education that fosters liberation—teaching people what they didn't even know they didn't know, operating through intellectual imagination—springs from asking why teach.

We believe that history museum exhibits and programs are educational media comparable to school books. The question why teach therefore obliges the history museum to subject its public offerings to parallel scrutiny—do the exhibits and programs cultivate replication or liberation? Furthermore, we recognize that all historical interpretations, even scholarly ones, can be expected to be products of their own times, reflecting contemporaneous social and political forces. Therefore, museum visitors should be made aware of the current cultural context that inescapably shapes any historical interpretation. Moreover, we are convinced that the public should be encouraged to question rather than accept given interpretations. When a historical interpretation does not actively encourage challenges, it inevitably encourages acceptance of the often hidden social and political agenda it supports. Historical interpretations can thereby promote replication of the society that produces them.

Through the public program of "Archaeology in Annapolis" we try to liberate participants from dependence on unreflectively presented historical information for their understanding of the past. Our response to *why* teach: to help visitors become critical consumers of history rather than passive collectors of "true historical facts" which often serve hidden contemporary social or political agendas.

What We Teach

Ethnographic analysis, borrowed from cultural anthropology, holds that any human reality will have both a surface and a deeper meaning and that not all individuals in a particular setting may be conscious of the two levels of meaning. Ethnographic observation is eminently well-suited for revealing hitherto undetected patterns that—once understood—can be exploited, controlled for, or otherwise taken into account.

We believe that an ethnographic study of a specific history museum within its particular social and political environment isolates significant questions, while bringing into play a theory of society for formulating problems and analyzing results. Internally, ethnography could be used to answer any number of specific questions about the museum under study, but the large and useful ones would include how staff members made decisions about exhibits, whether there is a different message communicated by different media, how people remember what they are told in museums, and what creates the boredom so often found in museums. Externally, ethnography also suggests significant issues. Critical theory has been used to examine the relationship between a history museum's immediate economic and political environment and its exhibits in order to determine whether the museum encoded meanings from the modern world while seeming to educate about a past one.[4] Once an ethnographic study reveals such a relationship, the museum staff can decide whether the messages should be disentangled.[5]

The public program of "Archaeology in Annapolis" takes into account the results of a study of how Annapolis today thinks—and over the last century has thought—about its past.[6] Primary sources included interviews with local residents, tours of the city, historical talks given to a variety of groups, historical picturebooks and guidebooks, and fullblown histories of the city, to name a few.[7] Principal questions included: What time periods are stressed? Which individuals, classes, groups, and institutions are the objects of historical attention, and for whom? And most important: Which relationships among individuals and institutions are highlighted and which are ignored or concealed?

The key ethnographic finding is that history in Annapolis is fragmented. Eighteenth-century history is separate from nineteenth-century history; black history is separate from white history; the history of the city is separate from the history of the United States Naval Academy, located in Annapolis since 1845. Detailed analysis shows sharp contrasts between the city and the academy. Whereas the city is portrayed as old, eighteenth-century, brick, small, slow, evocative, and associated with the white part of the population, the academy is portrayed as modern, nineteenth- or twentieth-century, granite, large, fast, scientific, and associated with the black part of the population. At the same time, both the city and the academy claim to be nationally important, the city for its role in the birth of the nation, the academy for its role in national defense and its national student body.

This emphasis on national role by both the city and the academy shortchanges the historical relationship between the two. Annapolis, founded around 1650 and named capital of Maryland in 1695, has commemorated since the 1880's a "Golden Age" (circa 1760 to the mid-1780's) that culminated dramatically in two important events that occurred in the Old Senate Chamber of the Maryland State House—George Washington's resignation of his commission in the ContinentalArmy and the ratification of the Treaty of Paris with Great Britain.[8] The Naval Academy, on the other hand, was founded in 1845 and regards itself as a big, progressive university—not as a historic site. Both city and academy ignore their 140-year-long relationship.

We have developed a hypothesis that suggests that neither city nor academy finds it advantageous to acknowledge a common history. Annapolis, economically dependent on the Naval Academy, has been dominated in real estate transactions by the academy. Ten times the Naval Academy wanted land from the city for expansion; nine times Annapolis acquiesced. Only once, when Historic Annapolis established in 1963 the historic value of three city blocks adjacent to the academy, was expansion halted.[9] In all likelihood the city downplays the history of its connections with the academy from wariness of further expansion by the academy. And the academy sidesteps its historical relationship with the city for fear of appearing the menacing neighbor. Both Annapolis and the Naval Academy sustain a myth of historic autonomy to advance their individual self-interest. Each, therefore, according to critical theory, presents an incomplete version of the past that accentuates separation, effectively according separation an aura of inevitability that is both ahistorical and inaccurate.

It has been contended that social life today functions on the basis of separations—time units like centuries, social units like ethnic groups or economic classes, and spatial units like plans.[10] Customarily taken as givens, normally unexamined, these separations can nevertheless be shown to have histories that render them subject to challenge and change by the knowledgeable. Through the public program of "Archaeology in Annapolis" we try to share observations of the contempory, local social and political environment derived from ethnographic analysis. Our resonse to *what* to teach: the masking of a present and a past reality in traditional treatments of Annapolis' history.

How We Teach

The objective of liberating the audience and the content of challenging customary historical interpretations equally underlie and thematically unite the three-part visitor experience that constitutes the public program of "Archaeology in Annapolis." Two hours in length, "Archaeology in Public" consists of an audio-visual presentation, a guided tour of an archaeological site under excavation, and a self-guided walking tour of one part of the Historic District of Annapolis:[11]

* Twenty-minute multi-projector audio-visual presentation, *Annapolis: Reflections of the Age of Reason*, to be screened in a visitors center, highlights how the increasing balance, symmetry, segmentation, and standardization that characterized late eighteenth-century English and American material culture transcended the aesthetic by shaping not only the things people used but also their very lives, thereby facilitating profit-making in eighteenth-century Maryland.
* Fifteen-minute tour, with question period, of an archaeological site, conducted by a working archaeologist.
* Ninety-minute self-guided walking tour of eight locations around the city, contained in a 24-page guidebook, *Archaeological Annapolis: A Guide to Seeing and Understanding Three Centuries of Change*,[12] that not only gives the contemporary interpretations of each location but also clarifies how its historical meaning has changed and continues to change in conjunction with needs, opinions, tastes and politics.

Although the ideal visitor experience would follow the order above, the three components—using different data and media—are intended both to stand alone and to complement one another. The underlying and unifying theme of liberation and challenge is particularly compelling when delivered by a dirt-stained, working archaeologist discussing with the visitor how he or she is thinking about a site that very day. We are confident that finished and beautifully-designed exhibits filled with research conclusions dressed up as "true facts" are not nearly as effective for cultivating critical consumers of history who intelligently question received historical interpretations. Our response to *how* to teach: to have archaeologists speak directly to visitors, presenting the methods for learning about the past instead of the fixed results of historical and archaeological research, meshed with an overall experience that provides context for viewing and weighing historical and archaeological evidence.

Sample Guided Tour

In April and May 1985 "Archaeology in Annapolis" excavated the eighteenth-century yard of the State House Inn, on State Circle, about 150 feet from the Maryland State House, in order to find evidence of the original perimeter of State Circle.[13] The current "circle" is actually a lumpy oval 30 to 60 feet narrower than the original, true circle laid out as part of Governor Francis Nicholson's town plan in 1695 (See figures 1 & 2).

After introducing herself, the crew, the project (including key sponsors), the site and archaeological techniques, the archaeologist/guide calls attention first to the State House across the street and then to a clear profile in a 15-foot-long trench that shows the eighteenth-century contour of the hill on which the State House still sits. She points out a line of post holes, marking the boundary of an earlier, larger cir-

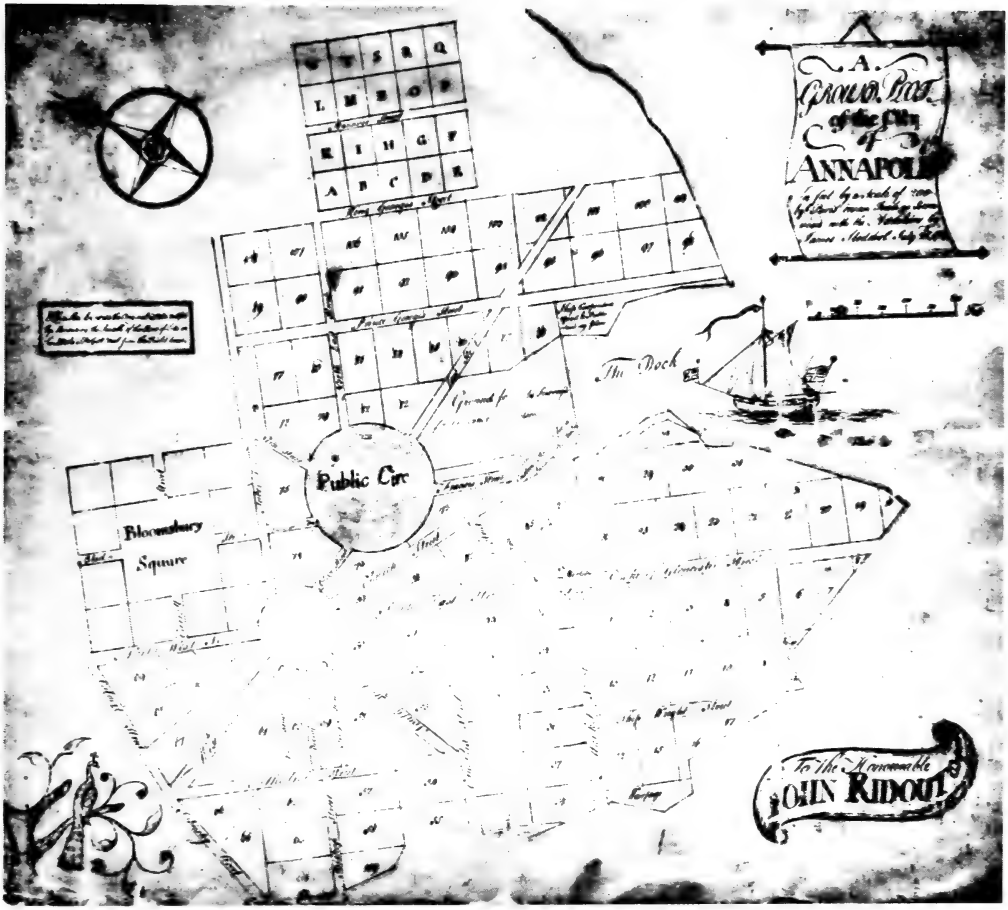

Fig. 1. An early 18th century ground plan of Annapolis. Note the roundness of the two circles. (Photo by M. E. Warren)

cle; these signify alterations, like those on the other side of the circle, 700 feet away at the Governor Calvert House site, where there is archaeological evidence for one to three feet of cutting and as much as 12 feet of filling on the edge of the circle.[14]

There have been many such minor modifications but only one major exception, the archaeologist/guide explains, to Governor Nicholson's original plan, which featured two circles with streets radiating from them. Keeping in mind that this baroque street plan not only served to make property lines clear (as would any well-surveyed town plan), but also served to focus attention on the two buildings inside the circles—the State House and St. Anne's Church—as architectural symbols of the two centers of power in colonial Annapolis and Maryland, the 1695 street plan was not simply a product of traffic flow or convenience but rather a device to identify and *enhance* authority. It was, and is, active and even political. Today, throughout the city, the State House continues to be the visual focus of attention from almost all the streets, which still radiate as they did in the late seventeenth-century. The exception is the United States Naval Academy. When it was founded in 1845, the academy used a part of the 1695 plan, but between 1900 and 1910 it was rede-

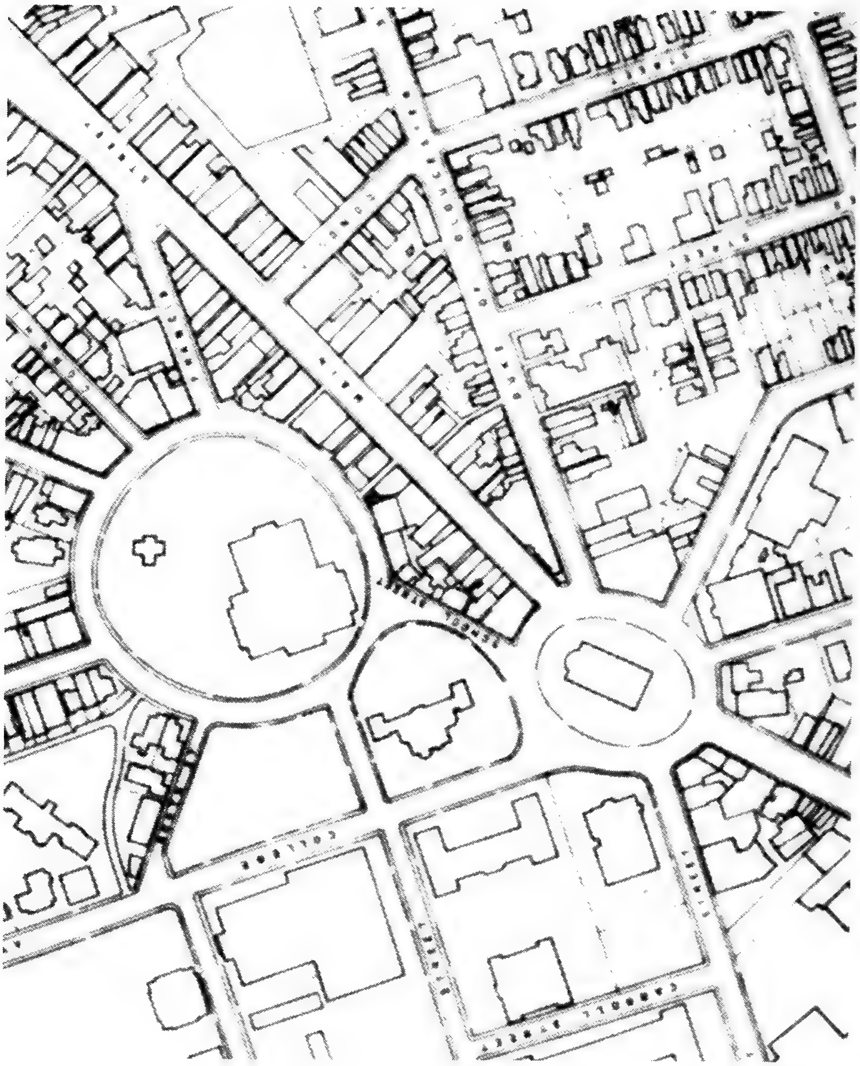

Fig. 2. Annapolis today. Note how the circles are no longer round. (Photo by M. E. Warren)

signed and now has its own separate, self-contained street plan that focuses on itself and on the adjacent Severn River. This design obliterated a part of the original plan and abandons the State House and St. Anne's as focal points.

The academy campus, like the excavated post holes pointed out by the archaeologist/guide, represents alteration in the town plan, even though the separation between Annapolis and the Naval Academy, signaled so sharply by the architecture, seems timeless today. Indeed, for the academy not to have its own plan, for it to employ Governor Nicholson's focal points, would constitute a symbolic subjugation of a federal institution to the State of Maryland, a patent absurdity to the academy. The guided tour conducted by the archaeologist/guide thus provides some of the requisite information for making the relationship between Annapolis and the Naval Academy an issue rather than an established fact.[15]

Beginning with standard archaeology, the guided tour could have presented the street plan as an anachronism, a lovely relic unchanged since 1695, or a simple American version of city plans carried out in Europe since the fifteenth century. But such verbiage would only have duplicated the fragmented presentations customarily given of Annapolis's past while obscuring the active use of space and sight lines to keep power within the separate hands it has, by agreement, come to reside. Instead, the guided tour was shaped by a decision to teach a specific message about how material culture has been, and continues to be, manipulated in Annapolis.

The guided tour stressed that the two political or social segments of the city use space and its divisions, ordinarily taken to be neutral, as part of the management of power. A street plan, it becomes clear, may handle vision in a way that enforces political separations and demonstrates their truth. We wished the guided tour to teach something explicit and connected to the present, to avoid replicating society in an unreflective fashion, and to disclose the history of a hitherto unquestioned separation through archaeology. The attentive visitor might then be aware of what society is asking him or her to do by "learning" history, and awareness might lead to action.

How, What, and Why Recap

Since the summer of 1982, five different archaeological sites with guided tours like the one described above have been opened. Each guided tour is specific to the site on which it is given, in accord with its location, history, preliminary findings, and stage of excavation. In four seasons over 25,000 people have participated in "Archaeology in Public" guided tours. There is no doubt that this public program slows down excavation. On-demand tours, as many as 40 a day given to an average group of fewer than six, are both very labor intensive and expensive. Nonetheless, our 10%-level of visitor evaluation suggest that the investment is worthwhile. The evaluations verify that we are teaching visitors not only about particular archaeological sites but also about questioning archaeological presentations, and consequently, other presentations of history. And that is our real goal.

In each of the media we use, we make an issue of method, the contemporary logic applied to things from the past. A focus on method encourages the visitor to question and challenge an interpretation. *How* we teach, therefore, endeavors to keep "Archaeology in Annapolis" from being simply another tool for replicating society and maintaining an unexamined order. We stress our active participation in the creation of the past. *What* we teach derives from studying the ethnography of the local community because, contrary to the impression given by many American historical museum settings, the creation and consumption of the past are neither neutral nor passive. People and groups use history to keep what they have and to get what they want from others. We recognize that the line between what we teach and how we teach may seem indistinct. In fact, we readily acknowledge that how we teach is a part of what we teach. Finally, *why* we teach exemplifies Carl Becker's idea that "everyman is his own historian."[16] The public program of "Archaeology in Annapolis" eschews creating and propagating just another version of the past. We are trying to teach people how to keep history from being done to them.

Acknowledgements

An early version of this paper was presented by Leone as "Material Culture as Education" at the Sixth Museum Conference, "Education Programs: What Role in Museums," on April 13, 1985, at the University of Delaware. Potter has received considerable assistance in his ethnographic research from the volunteers and staff of Historic Annapolis, Inc. Principal sponsors of "Archaeology in Public" include the Maryland Humanities Council (Grants 546, 601-E, 738-F, and 760-G), the National Endowment for the Humanities (Grant GM-21645-83), and the Maryland Heritage Committee.

Notes:

1. The project depends heavily on the preexisting historical work with city and county records done by the historical school led by Dr. Lois Green Carr and including Dr. Lorena Walsh, Dr. Jean Russo, and Ms. Nancy Baker.
2. **M. P. Leone** 1983. "Method as Message." *Museum News*, 62(1): 34–41; **Potter, P. B. Jr. and M. P. Leone.** "Archaeology in Public in Annapolis: Four Seasons, Six Sites, Seven Tours, and 32,000 Visitors," *American Archaeologist*, in press.
3. **R. M. Elson** 1964. *Guardians of Tradition*. University of Nebraska Press, Lincoln.
4. **M. P. Leone** 1981. "Archaeology's Relationship to the Present and the Past." In *Modern Material Culture: The Archaeology of Us*, R. A. Gould and M. B. Schiffer, eds., Academic Press, New York. pp. 5–14; **Leone, M. P.** 1981. "The Relationship Between Artifacts and the Public in Outdoor History Museums." In *The Research Potential of Anthropological Museum Collections*. A. Cantwell, J. B. Griffin, and N. A. Rothschild, eds., *Journal of the New York Academy of Sciences*, 376: 301–313.
5. **R.S.Baranik, S.Bromberg, S.Charlesworth, S. Cohn, C. Duncan, *et al.*** 1977. *an anti-catalog*. The Catalog Committee of Artists Meeting for Cultural Change, 106 E. 19th St., #4, New York, NY, 10003; **M. Wallace** 1981. "Visiting the Past: History Museums in the United States." *Radical History Review* 25: 63–96; **D. Meltzer** 1981. "Ideology and Material Culture." In *Modern Material Culture: The Archaeology of Us*, R. A. Gould and M. B. Schiffer, eds., Academic Press, New York. pp. 113–125; **J. M. Gero, D. M. Lacy** and **M. L. Blakey (eds.)** 1983. "The Socio-Politics of Archaeology." *Research Report 23, Dept. of Anthro., University of Massachusetts at Amherst*; **R. G. Handsman** 1984. "How to do the Archaeology of the Center Village of Litchfield." *Artifacts* XII(4): 2–7.
6. Potter's work has been preceded by several unpublished preliminary ethnographic studies of history in Annapolis: **C. Quinn** 1982. "Notes for a Walking Tour of Annapolis." Term paper, Dept. of Anthro., University of Maryland at College Park. On file at Historic Annapolis, Inc., (HAI) Annapolis, Maryland; **J. H. Ernstein** 1985. "Interpretations of History in a Living Historic Town." Term paper, Dept. of Anthro., Boston University.

On file at HAI; **N. A. C. Holman** 1985. "Close Encounters of the Historical Kind: A Personal Account of a Summer Spent Looking at the American Past." Research paper, Dept. of Archaelogy, St. Catherine's College, Cambridge. On file at HAI; **L. Topper** 1985. "Public Archaeology in Annapolis." Term paper, Dept. of Anthro., George Mason University. On file at HAI.

7. Potter has lived and researched in Annapolis for 30 months. His data base includes four booklength histories of the city, 20 guidebooks, a dozen formal interviews, hundreds of hours of informal interaction, attendance at a half-dozen major historical celebrations and over two dozen historical lectures and special tours, participation as both a student and teacher in the Historic Annapolis interpreter training program, as well as regular service as an HA interpreter.
8. **R. G. Handsman** and **M. P. Leone.** "Living History and Critical Archaeology and the Reconstruction of the Past." For *Critical Traditions in Contemporary Archaeology*, V. Pinsky and A. Wylie, eds., in press, Cambridge University Press.
9. Historic Annapolis, Inc. 1963. *Three Ancient Blocks of Annapolis, Maryland's Capital City*. HAI, Annapolis.
10. **G. Lukacs** (1922) "Reification and the Consciousness of the Proletariat." In *History and Class Consciousness* by G. Lukacs, M.I.T. Press, Cambridge. pp. 83–222; **J. Habermans** 1971. *Knowledge and Human Interest*. Beacon Press, Boston; **S. Barnett** and **M. Silverman** 1979. *Ideology and Everyday Life*. University of Michigan Press, Ann Arbor.
11. Designed by Philip Arnoult, a media consultant.
12. **M. P. Leone** and **P. B. Potter, Jr.** 1984. *Archaeological Annapolis: A Guide to Seeing and Understanding Three Centuries of Change*. University of Maryland and HAI, Annapolis.
13. **J. W. Hopkins III** 1985. "Preliminary Report on the Excavations at the State House Inn Site." Ms. on file at HAI.
14. **A. E. Yentsch** 1983. "Salvaging the Calvert House Site." Final report for NEH grant RO-20600-83. On file at HAI.
15. The tour of the State House Inn site was offered from 9:00 until 4:00, Monday through Saturday, from April 22 through June 1, 1985. The basic tour was directed toward adults but we also created a special version for fourth graders field tripping in Annapolis as a part of their study of Maryland history. The tours followed the format developed in 1982 (see note 2). The tour was given by two of the five archaeologists working on the site, Pamela Henderson and Kristen Peters, and was presented to more than 4,300 people in six weeks.
16. **C. Becker** 1935. *Everyman His Own Historian*. Quadrangle Books, Chicago.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 106–114, June 1986

Making Sense of Art

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Even novice museum-goers suspect that there is something to be learned from simply looking at art, something which words cannot convey. Yet this "something" perplexes many people, who assiduously read labels and listen to recorded tours, hoping to unlock the mysteries of art. "This is what you are seeing" all too often substitutes for actually looking at artworks (Fig. 1). But words alone do not seem to provide the key.

René Magritte's painting, *The Betrayal of Images* (Fig. 2), plays upon the differnce between words and images: below the image of a pipe the words "this is not a pipe" are prominently displayed. This pronouncement boldly refers to the reality of the painted surface. The painting is not a pipe because it is a painting. And painting, Magritte implies, has a language all its own that differs from, and even contradicts, linguistic messages.

While it is a well-known truism that a picture is worth a thousand words, modern culture depends on words and the information they convey. As Magritte slyly points out, images speak, but not in the same way as words. Verbal information has been described by anthropologist Edward T. Hall as "low-context" because, once the code or language is known, it requires little previous experience to be understood.[1] But information about an artist's life or about the history of a particular object or its style is very seldom useful without the knowledge of how to apply it.

Art objects are "high-context" forms of communication, conveying complex ideas that go well beyond the immediately visible and easily decipherable stories that some paintings seem to depict. According to Hall, in a high-context message or communication, "most of the information is either in the physical context or internalized in the person, while very little is in the coded, explicit, transmitted part of the message."[2] Consequently, to make sense from a confrontation with an original work of art, the viewer has to be willing to question, analyze, and think critically—that is, to be able to make educated decisions and judgments about what he or she is seeing. What the museum visitor brings to the process of interpreting art, therefore, is of paramount importance.

Art that tells a story—through its resemblance to readily-absorbed low-context information—attracts people with little or no experience in interpreting artworks. One of the most popular paintings in the National Gallery of Art is John Singleton Copley's *Watson and the Shark* (Fig. 3). Its story is obvious: a young man in the water is being attacked by a vicious killer shark while several men in a boat attempt to rescue him. The drama of the scene is easily perceived and the image

Fig. 1.

Fig. 2. René Magritte, "La Trahison des Images (ceci n'est pas une Pipe)" or "The Betrayal of Images (this is not a pipe)" 1928–29. Los Angeles County Museum of Art, Purchased with Funds Provided by the Mr. and Mrs. William Preston Harrison Collection.

evokes the feeling of excitment often sought in adventure movies and novels. Moreover, in addition to the recognizable action, a lengthy description printed right on the frame identifies the man in the water as Watson and recounts his survival of the shark's attack, overcoming the loss of a leg to become a fine, upstanding citizen. These facts, while appeasing the desire of most visitors to know what a work of art is about, are only marginal to what is communicated visually by the painting itself.

Exploring the realm of the visual connotes considering how a painting—a static, two-dimensional surface with lines and colors on it—conveys so much drama and emotion. Certainly the gestures and expressions of the people depicted in *Watson and the Shark* help to communicate urgency. But equally important is the network of intersecting diagonal lines underlying the human forms and the play of lights and darks across the surface. The nude Watson is very bright, as are the two figures reaching for him, while the evil shark emerges from the shadows. There are few rounded, cuddly shapes in the painting but many jutting edges and sharp angles. All these elements of design contribute to the overall dramatic effect.

Copley has also been rather clever in communicating the action. A painting, unlike a story, does not take place in time. To communicate a narrative, the artist has to arrange his figures, colors and shapes to enable the viewer to see certain parts of the composition before others. In *Watson and the Shark* the nude body is one of the first things to be noticed, then the menacing shark. Following awareness of the imminent danger, the viewer's eye travels up the two standing figures in the

Fig. 3. John Copley, "Watson and the Shark," 1778. National Gallery of Art, Ferdinand Lammot Belin Fund.

boat which form the apex of an acute triangle that pulls the eye away from Watson and the shark just enough to draw attention to the man with the spear about to do in the evil attacker. Will he get the shark before the shark gets Watson? Copley artfully placed the tip of the harpoon at the same distance from the shark as the shark's nose is from Watson. Only the inscription of the frame resolves the suspense. The visual information, communicated by the composition, combined with literal information, completes the story of the painting.

Visual information, however, is not always interpreted in the same way. Today's viewers looking at *Watson and the Shark* probably react quite differently from their eighteenth-century counterparts. More easily than current museum-goers, Copley's contemporaries would have sensed that this painting concerned not just a man and a shark, but rather referred to the triumph of Good over Evil. Copley ensured this association by "quoting" from famous masterpieces as well-known to art lovers of his time as the Mona Lisa is known today: the man about to spear the shark is borrowed from a Renaissance painting by Raphael of the angel Gabriel defeating Satan, and Watson himself closely resembles an ancient statue, the Apollo Belvedere, that embodied ideal beauty. Furthermore, eighteenth-century viewers—unaccustomed to seeing far away places—would have been very curious about and appreciative of the accurate detailing of Havana harbor where the scene takes place, while contemporary viewers, familiar with the movie *Jaws*, may note that the shark does not appear very realistic. Today's museum-goer may find Watson's nudity a bit funny or discern that, in spite of the action, the painting, in the final analysis, appears quite static.

The rich diversity in human response further complicates culturally-determined differences in perceptions and ideas like common knowledge of Raphael's angel Gabriel vis-à-vis Spielberg's mechanized shark. Different people can react quite differently to the same object: consequently, art works do not always convey the same message to everyone. Studies show, however, that visitors going through art museums on their own, without a guide, spend only one or two seconds in front of each object. Clearly this is not enough time to engage in active looking at the artworks and registering their effects. But additional time spent reading labels or brochures seldom results in an understanding of the high-context language of art. Can the museum as an institution teach people the questioning, analytical and thinking skills they need in order to unlock the mysteries of art?

There are three basic activities all visitors, consciously or unconsciously, undertake in an art museum: identifying, comparing and judging. While these processes occur as a matter of course in any setting, the nature of the museum as a learning environment lends them special significance. The visitor comes to the museum primarily to see things; the act of perceiving is thus more acutely in focus.

The first activity—identifying—may consist simply of naming what is seen as a painting, a sculpture, a piece of furnitire, etc. Or, it can be more complex, reflecting the viewer's previously acquired knowledge. Beginning art history students, for example, like to impress friends and family by identifying a particular artist's work without looking at the label. But the identification game need not be regarded solely as an opportunity for swaggering. In today's culture, so flooded with posters, color plates and postcards of artworks, the act of identifying corresponds to finding what John Berger calls "the original of the reproduction."[3] Many museum-goers have experienced the genuine satisfaction of seeing in the flesh works of art recognized from advertisements, books, or television.

The second activity—comparing—is often closely linked to the process of identifying. Since a relationship is automatically established between or among objects when they are displayed together, museums inevitably foster comparisons. Two portraits by different artists may be hanging in the same room; a single gallery may show a number of works by the same sculptor, allowing viewers to trace the artist's stylistic development; decorative arts from one country may be installed in close proximity to a period room of the same century from another country.

The third activity—judging—is the process of deciding what is liked or disliked, choosing among the objects that have been identified and compared. In the art museum this process is sometimes somewhat thwarted by the fact that the objects have been—both in principle and in practice—already identified, compared, and judged. Everything that is exhibited is "good" art. Nevertheless, people have an innate tendency to show preferences and make choices.

These three fairly commonplace activities—identifying, comparing and judging—are tools which may be effectively used to sharpen questioning, analytical and critical thinking skills in the art museum. The art museum educator can let people know that they are carrying out these processes and can encourage more thoughtful identifying, comparing and judging. Mere identification, for instance, is not as simple as it seems, since seeing and knowing are intimately interconnected. A friend can be recognized from a great distance, before his or her facial features can actually be seen. On the other hand, a lack of familiarity with an object or person can cause certain important pieces of encoded information to be overlooked.

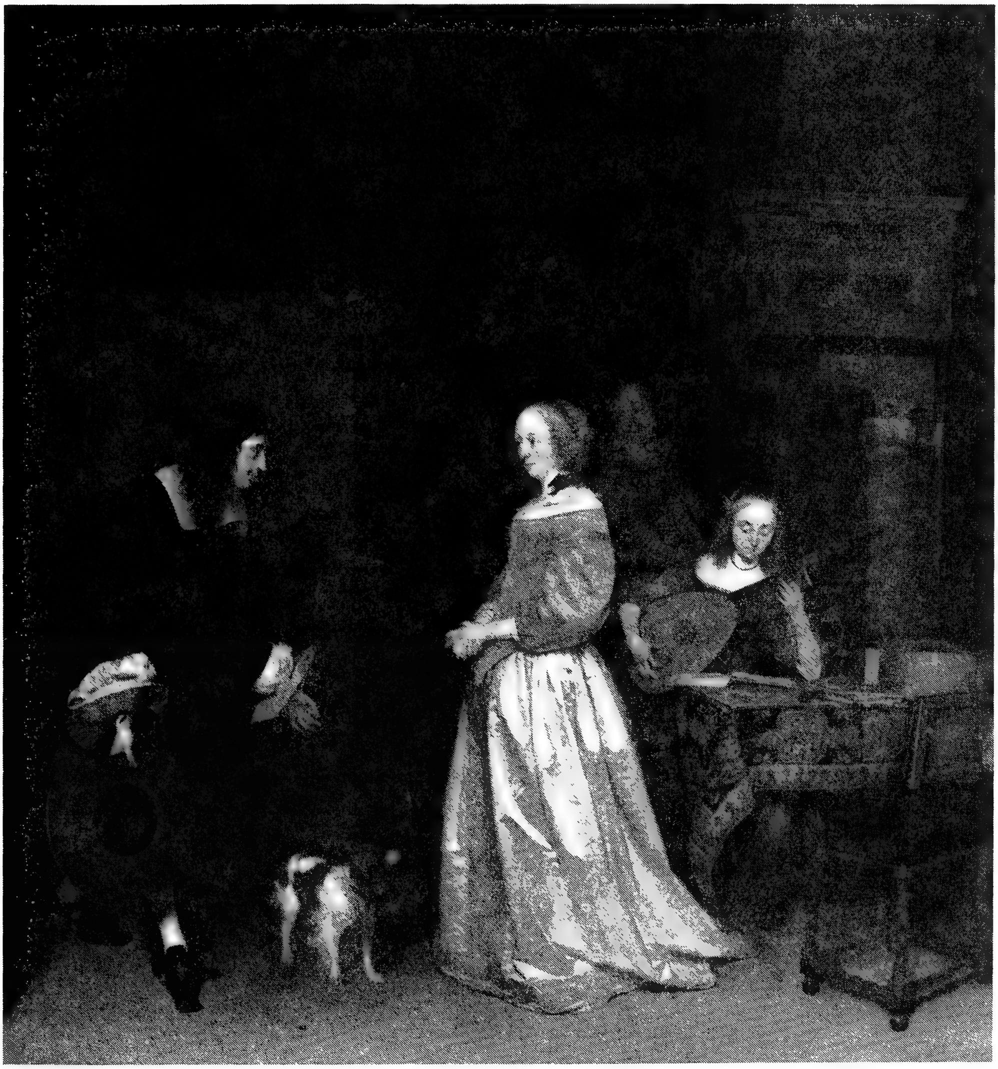

Fig. 4. Gerard ter Borch, "The Suitor's Visit," c.1658. National Gallery of Art, Washington, Andrew W. Mellon Collection.

For a long time the National Gallery's painting *The Suitor's Visit* (Fig. 4) by the Dutch seventeenth-century artist Gerard ter Borch, was believed to represent a young woman receiving her fiancé in the company of her parents. The title encouraged a rather hasty identification of the major characters in the scenario: fiancé arriving, mother greeting, shy young woman playing the guitar, and father hovering in the background. But a more careful look reveals some problems with this script. The women in the painting appear to be the same age—perhaps they are sisters. However, the figure in the shadows, previously identified as the father, does not seem much older than the ostensible suitor. And how can the figures in the painting be identified with confidence today given unfamiliarity with the dress of the period that virtually precludes intuiting the subtle messages that costume conveys? In fact, recent scholarship believes the scene to be a brothel: the suitor is a client; the young girls, prostitutes. Yet even this hypothesis leaves many unanswered questions, for how is the calm, elegant atmosphere communicated by the work to be reconciled with customary expectations and assumptions about brothels? Thus, instead of providing easy answers, the process of identification can often lead to some of the deepest questions about artistic intent or cultural context.

Comparisons are often set up for the visitor by the judicious juxtaposition of artworks. The art museum educator can exploit the closed system of a comparison to demonstrate a number of relationships and interconnections. The museum-goer's questioning how objects are similar and dissimilar can lead to a deeper understanding of stylistic developments, individual vision and national identities.

Finally, evaluating and making educated judgments—essential for visitors—challenges the art museum educator. All too often museum-goers will assert defensively that "they don't know much about art, but they know what they like" to allay their fear that what they like may not be considered good enough by museum authorities. Such rigidity is unfortunately detrimental to the learning that can and should take place in the art museum.

Absorbing, processing, and then applying information perceived through all the senses constitutes learning. Processing involves matching the newly-acquired perceptions and information to a cognitive orientation shaped by previous experiences and a conditioned way of seeing the world. Perceptions that are unmatched may go unnoticed, simply not registering in the consciousness of the individual as information.[4] But when the matching is even partially successful, the individual will begin making sense of the information he or she has received. Making sense often requires the revision of preexisting assumptions and ideas, and this revision enables the individual to apply the newly-acquired, newly-integrated material to his or her actions and behavior.

Although all three steps are essential to learning, processing seems to be especially significant. Psychologist George Miller has pointed out in *Psychology: The Science of Mental Life* that during this part of the mental operation, the "organism struggles to reduce the mismatch between its own criteria and perceived reality."[5] Information that fails to match may be discarded quickly. But if the individual is willing to endure what Morse Peckham calls "cognitive tension" (discomfort from the sensation that something is wrong), then learning occurs.[6] Individuals who can examine with some objectivity the disparity between new information and their own internal order are able to try a number of different ways to resolve the mismatch; ultimately they come up with solutions that are innovative and unique.

When museum visitors see an art object with which they are completely unfamiliar, cognitive tension occurs. In fact, cognitive tension is present in varying degrees for most visitors in front of most art objects most of the time. Why else would people turn so eagerly to recorded tours, labels, and other forms of low-context information in order to make sense of the high-context experience of looking at art? Art museum educators, in addition to providing ready information about art, should encourage visitors to endure the discomfort of not knowing the "right" answer immediately in order to learn to make educated judgments on their own. The museum is a safe place in which to endure ambiguity, to rehearse navigating through today's complex world.

Contemporary art is an especially effective tool for teaching evaluative thinking; individual taste in direct conflict with institutional judgment generates considerable cognitive tension. Abstract or nonrepresentational art objects, incomprehensible to many people because they thwart even the relatively simple process of identification, not infrequently fail to match visitors' assumptions about the definition of art. Furthermore, contemporary art—reflecting through its diversity the pluralism of values existing in today's society—challenges the notion that museums offer a single, absolute definition of art.

Museums, by presenting themselves as neutral contexts for the viewing of art, are partly to blame for fostering certain false assumptions that ultimately discourage visitors from exploring more fully issues of quality and value. In their effort to collect and show the highest quality objects, museums often give the impression that their definition of quality is indeed the only one possible. Museum professionals seldom reveal in their installations and publications the human decision-making mechanism, with all its ambiguities and inconsistencies, that underlies the acquisition, exhibition and interpretation of art. For visitors to begin making educated judgments, they need to apprehend both that individual works of art—as well as entire institutions—are dependent upon people making decisions and choices and that their own choices are valid and worthwhile; institutional taste is not absolute. Thus, although museums may naturally encourage certain perceptual skills—identifying, comparing and judging—that can stimulate critical thinking, they also project an authoritative neutrality that hides the human components of the institution, thereby undermining the visitor's confidence in his or her own competence to think, analyze, and consider the meaning of art on his or her own.

Labels, brochures, recorded tours, interactive computers, and audio-visual programs provide visitors with useful information about art. But these low-context forms of communication fall short of illuminating the high-context experience of understanding art. Making sense of art is only possible through the visitor's active engagement in looking, thinking and reflecting. For the uninitiated museum-goer, given the novelty and complexity of viewing art as a high-context expression, mediation by another person can be beneficial. While this job is currently performed by museum educators, all people can learn to help one another notice, compare and evaluate.

Art museum educators can humanize the museum environment by reminding visitors that an institution is only the sum-total of the people who run it. More important, art museum educators can encourage visitors to endure cognitive tension, to reserve judgment, and to undertake the process of evaluative thinking. By listening with a sympathetic ear to visitors voicing their feelings of discomfort, an art museum educator can help to validate their opinions. Forewarning visitors that they may dislike what they see or doubt that it is art serves to encourage visitors to consider their own system of assumptions and beliefs in comparison with institutional judgment about contemporary art.

The arts have traditionally played the role of inspiring, educating and uplifting. Since many visitors regard art museums as educational institutions, they come with the expectation of learning something. But learning from objects is not limited to absorbing information about them. Instead, it centers on thinking about important issues like perception and values, resolving difficult problems while enduring the discomfort of cognitive tension, and asking deep questions about the meaning and content of works of art. Visitors treated with respect by museum staff and challenged to consider the variety of complex questions that the interpretation of artworks poses respond very well. Perhaps it is time for art museums to stop selling themselves and their audiences short by limiting their interpretive materials to shallow answers for narrow questions. Visitors eager to be told "This is what you are seeing" might be better served if their attention were gently drawn to the object itself and to the myriad of complex feelings and questions engendered by looking, thinking and reflecting.

Notes:

1. **Edward T. Hall,** *Beyond Culture* (New York: Anchor Books, 1977), p. 91.
2. Ibid.
3. **John Berger,** *Ways of Seeing* (London: BBC and Penguin Books Ltd., 1972), p. 21.
4. Piaget's famous experiments with children prove that some types of information cannot be processed until the proper cognitive structures have developed. **Jean Piaget,** *The Child's Conception of Physical Causality* (New Jersey: Littlefield, Adams & Co., 1972).
5. Cited in **Morse Peckham,** "Art and Disorder," in *Esthetics Contemporary*, edited by Richard Kostelanetz (New York: Prometheus Books, 1978), p. 101.
6. Ibid.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 115–121, June 1986

Playful Learning for All Ages: Participatory Exhibits

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Traditionally, museums make multitudinous decisions for the visitor. Curators and exhibit designers customarily decide what artifacts are exhibited, what information is featured, and how the presentation is made. Much of this unilateral decision-making is, of course, warranted and expected: the museum staff alone have the professional expertise to determine the physical condition of an object and how best to display it. The museum visitor's decision-making is characteristically limited to reading none, some, or all of the label copy. By largely excluding the visitor from an active role in directing his own learning, the museum frequently does itself and the public it aims to educate a great disservice.

But what happens when the visitor is permitted, even provoked, into an active role in directing his own learning?

"This was fun!" exclaimed a middle-aged woman from Kansas.

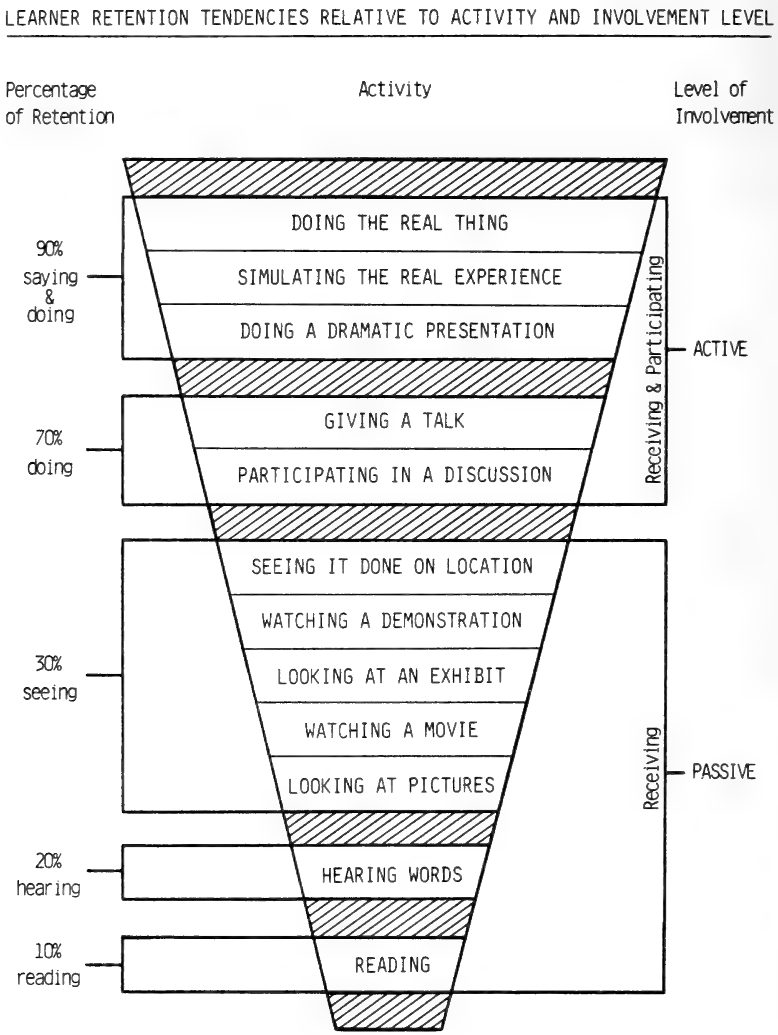
"This has been a very enjoyable experience," remarked a Massachusetts businessman.

"There should be more exhibits which we can participate in," recommended a doctor from Vermont.

These three remarks attest to visitors' satisfaction after enjoying artifacts on a one-on-one basis.[1] Instead of just *looking* at the artifacts, the visitors were given the opportunity to *interact* with them. Instead of being told not to touch, they were encouraged to pick up, manipulate, smell, taste or try on the artifacts. In many cases this hands-on freedom allowed the visitors to answer their own questions: What is it made of? What does it feel like? How heavy is it? Can I make it work by myself? What does the hallmark say on the bottom? Can I bend over with this on?

From their comments, it is clear that these visitors appreciated being able to tailor their museum learning experience to fit their personal needs. Regardless of their background knowledge, they had been offered the time, environment and materials to pursue their own agenda for learning from museum artifacts. They had all, in fact, been actively involved in a facsimile participatory exhibit.

Participatory exhibits are not new—a school outreach program of touch exhibits was conducted by the American Museum of Natural History in New York in 1909. Although educators observed improved learning, they lacked the instruments to document it. Over the past fifteen years, however, the developing field of museum evaluation has enabled American museums to investigate how to make their exhibits educationally more effective. Re-



Adapted from The National Park Service: Courtesy of Colonial Williamsburg.

Fig. 1.

search findings on both visitor behavior and the museum learning process increasingly indicate that the participatory exhibit, and especially the discovery room format, can successfully arouse and assuage the visitor's curiosity. This growing body of data, combined with society's rekindled interest in improving education, has led to the rapid proliferation of participatory exhibits. *The National Directory of Discovery Rooms,* begun by the Smithsonian's National Museum of Natural History in 1984, now has more than one hundred listings. This suggests that approximately one in fifty museums in this country operates a participatory exhibit.

The late Dr. Frank Oppenheimer, founder and director of the San Francisco Exploratorium, once said, ". . . in order to have good learning and even good enjoyment, you have to be able to make some decisions."[2] Participatory exhibits can help museums facilitate and increase visitor involvement in and control of the learning experience. The participatory exhibit is rooted in the philosophy that the more the learner is immersed in his own learning, the greater will be his capacity to comprehend and recall:

I hear and I forget.
I see and I remember.
I do and I understand.
Chinese proverb

The higher the degree of learner participation, the higher the retention percentage tends to be (Fig. 1). As D. D. Hilke and John Balling of the Smithsonian's Office of Educational Research point out in their recent study of family learning behaviors in two different museum exhibits, "The success which individuals or groups experience in acquiring or transferring information in a particular environment depends not only on the behavioral strategies which they bring to the task of learning, but also on the opportunities the environment provides for pursuing such strategies."[3] The variability of the visitor's learning preferences needs to be mirrored in the museum's exhibit format.

Looking at collections fails to satisfy fully. Since our high-tech society furnishes everything artificial from hearts to humus, communion with the genuine artifact is cherished. Dr. Caryl Marsh, founder of the Discovery Room at the National Museum of Natural History and now at the National Archives and Records Service, reported in 1984 that "recent interviews with visitors to the National Zoological Park strongly suggest that now, more than ever, people are starved for experience with 'real things.' Stifled by synthetics, surfeited with electronic images, they crave contact with authentic objects."[4] Furthermore, in an evaluation study done at the National Museum of American History in 1982, visitors indicated their desire to interact with artifacts on their own terms, intellectually and physically. They repeatedly wanted to know *how* something worked.[5] Hilke and Balling also found in the families they observed that there was a "bias towards strategies which acquired information first-hand, and the augmented potential for acquiring information which accompanies utilization of such methods."[6] "Evidently, the preferred mode of acquiring particular information about the exhibit was to find out for one's self."[7] Visitors seem both to want and to need the first-hand experience with artifacts that participatory exhibits afford and foster. With its emphasis on individualizing the museum learning experience, the participatory exhibit may at first glance appear chaotic. However, an effective participatory exhibit is by definition a highly structured environment with carefully conceived activities and clearly articulated objectives.

A number of teaching techniques used in participatory exhibits have conventional pedagogical antecedents—finding matching pairs of objects, manipulating an artifact and guessing its use, or putting together a puzzle to form a solution. While these activities are often associated with child's play and are denigrated by some as overly simplistic or juvenile, Judy White and Sharon Barry of the National Zoo explain: "Learning can be, and is, a fun and exciting experience for people of all ages. Learning is not a process that occurs in just the classroom. We believe that play is an inherent part of learning. Thus learning and play, or education and recreation, two goals held by most zoos (and museums), do not conflict with each other. A zoo (or museum) can be a great place for playful learning."[8]

One of the earlier museum exhibits to exploit playful learning as a teaching method, the Discovery Room at the Smithsonian's National Museum of Natural History, was begun in 1974 as a temporary experiment that proved so successful it has been continued as a permanent exhibit. It now attracts over 100,000 visitors each year, and has served as the prototype for many participatory exhibits both in this country and abroad.

Physically, the Discovery Room is small (36 × 28 feet) but its high ceilings, three

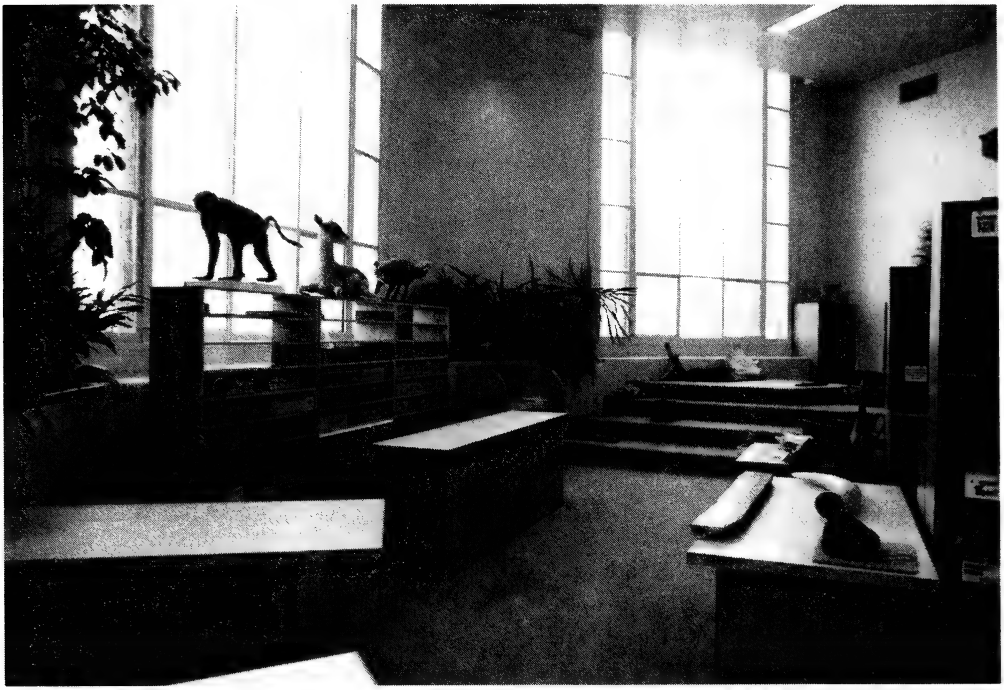


Fig. 2. The Discovery Room, National Museum of Natural History.

large windows and clear plexiglass window-wall give it a feeling of airy spaciousness (Fig. 2). The room is furnished with several tables and stools, a long counter, a carpeted platform, a microscope carrel and different types of open shelving. Large artifacts—a whale jawbone, wasp's nest and cannonball concretion—sit on the floor or hang from the walls and ceiling. These are called stumpers because they often outwit the visitor's imagination. Accompanying laminated cards tantalize the visitor by posing intriguing questions: "Who made it?" "What does it eat?" Detailed answers are given on the back of the cards. A popular stumper is the crocodile head—or could it be an alligator? Visitors are challenged to decide for themselves by using the information provided to examine the head for clues. Medium-sized artifacts like musical instruments, a freeze-dried rattlesnake, and a geode—also with information cards—are readily accessible on open shelving.

Smaller artifacts are organized in wooden discovery boxes. These are stored behind the counter and may be checked out from one of the volunteers who staff the exhibit. Each discovery box contains from six to twelve artifacts that relate to a specific theme. Included on the discovery box information cards are suggested activities which can further stimulate and guide the visitor's learning. In the *Queen Anne's Lace* discovery box, visitors can study a magnified encapsulation of the roadside flower while tasting its culinary cousins: caraway, cumin, coriander and dill. In the *Why Are You Sneezing?* discovery box, visitors handle fist-sized models of different pollen grains as they investigate the causes of many common allergies. With the *Minerals* discovery box, visitors can explore the properties of minerals by shaking (salt), flaking (mica), and writing (graphite) with them. If the cards do not satisfy the visitors' curiosity, they can turn to the small reference library in one corner of the Discovery Room or consult a staff member. If this does not suffice, they can write their questions on a stamped, self-addressed postcard for a response from a curatorial specialist. In some cases the Discovery Room collections are cross-referenced to other exhibits in the museum; visitors who have completed the *Coral* discovery box, for example, are encouraged to go see the living coral reef exhibit in the Sea Life Hall. This unobtrusive system of checks and balances ensures that the visitors' needs are readily met at every stage of exploration while allowing them the freedom to direct their own learning. Throughout the Discovery Room, information is made available in a variety of ways and at varying levels of difficulty to accommodate a wide cross-section of visitors.

Participatory exhibits similar to the Discovery Room at the National Museum of Natural History may be found in museums of all sizes, disciplines, and budgets. Five of the longer-established participatory exhibits in Washington are the Insect Zoo and the Naturalist Center—both also at the National Museum of Natural History—and ZOOlab, BIRDlab and HERPlab—all three at the National Zoological Park. The newest participatory exhibit, "Hands on History: An Open House of Eighteenth Century Activities" at the National Museum of American History, opened in November 1985 as part of AFTER THE REVOLUTION. The Insect Zoo is a living exhibit of insects housed in approximations of their natural habitats. Visitors can stroke a click beetle, closely watch a tarantula being fed, or observe bees energetically going about their business in a see-through plexiglass beehive. The Naturalist Center, which has an informal library atmosphere, offers visitors numerous study collections which they can research or use to compare and contrast with specimens they may have at home. Although each of the three participatory exhibits at the National Zoo—ZOOlab, BIRDlab, and HERPlab—has its own distinct character, they are all physically reminiscent of the Discovery Room at the National Museum of Natural History with tables and chairs, activity boxes, a reference library, knowledgeable staff and a congenial setting. As a group, the three labs chronologically reflect the changes and developments in participatory exhibits over the past eight years as the scientific study of visitor learning from artifacts has become an increasingly important part of exhibit design and planning.

ZOOlab, opened in 1977, replicates to a large extent the early Discovery Room. It is located in converted office space in the Education Building, a short walk from the animal houses. Given the desirability of closer proximity to the collections, BIRDlab, the second participatory exhibit, was opened in the Bird House in 1978. Despite its location, however, BIRDlab conceptually functions as an accessory. HERPlab, the newest participatory exhibit, was opened in 1982 in the Reptile House after copious visitor evaluation studies at several different sites. HERPlab is both physically and conceptually at the heart of the new Reptile House (Fig. 3) and employs established participatory methods in a stylish manner all its own: discovery boxes include selected live specimens (presented on a rotating schedule to give the animals the needed respite from curious humans); large glass doors permit the visitor to witness the daily routine of an actual keeper area; film loops and audio tapes complement the visitor's learning from artifacts.

Participatory exhibits are as yet a fledgling form of artifact presentation. While the field is rapidly expanding and new theories and methods are being formulated, much still remains to be studied, tried, and proven. Two of the greatest challenges facing developers of participatory exhibits are acquiring appropriate tangible artifacts and finding effective ways by which the artifacts may be used to facilitate the visitor's understanding of intangible concepts. Participatory exhibits have therefore tended to flourish in the sciences rather than the humanities. Scientific specimens are often more easily and inexpensively obtained, maintained, and replaced than

Fig. 3. Family interaction with a discovery box, HERPlab, National Zoological Park.

historical artifacts or artworks. Although participatory exhibits suffer remarkably little damage, a certain amount of wear and tear on the collections is clearly unavoidable. Whereas a natural history curator may not mind visitors' petting a common freeze-dried squirrel or assembling a turtle skeleton, no art curator will condone their poking an original work of art, nor a furniture curator their dismantling a seventeenth-century court cupboard. Moreover, conceptually, the sciences may be presented with greater objectivity and in more concrete ways than the humanities. A natural history discovery box may deal with the physical makeup of mollusks; it is not concerned with their morality. A zoological exhibit on fish may explain the spawning habits of salmon; it need not discuss a flounder's philosophy or the hidden message in a conch's collage.

Despite the problems of artifact rarity and conceptual complexities, a growing number of museums with humanities collections are attempting participatory exhibits. By building on the experience of science museums and by conducting and using evaluation studies on visitor learning, these museums are heralding the future of artifact interpretation in the humanities.

* At the Woodrow Wilson House Museum in Washington, D.C., the dining room is used as a form of participatory exhibit where the visitor can explore the Wilsons' style of entertaining. While no original artifact may be touched, visitors do gain a sense of personal involvement by casually walking around the room. Encouraged by a staff member, visitors discuss, among other topics, reproduction dinner menus of the period. Did they really eat all this? Who prepared the meal? Who served it? What does that say about social positions above and below stairs?
* At the *Then and Now Center* of the Plymouth Historical Museum in

Plymouth, Michigan, visitors investigate social, technological and economic changes over time in their community by comparing modern artifacts with older equivalents.

* *Sensation,* the extensive new participatory exhibit at the High Museum of Art in Atlanta, evolved from the premise that reality is experienced through the senses. Reality is therefore a perception and art a perceived interpretation of reality. Through a variety of sophisticated, multi-sensory participatory exhibits, visitors are led to reconsider their view of the world around them. The five sense organs are depicted as giant sculptures which can be walked through, smelled, felt and heard. A Honda car replica produces music when its trompe l'oeil marblelized chassis is touched. In a participatory, prismatic video-sculpture exhibit, visitors' movements are transformed into various colors, shapes and patterns. Is art really reality or is reality really art? Whatever personal conclusions visitors draw, they have been enthusiastic about participating in *Sensations's* mixed media, inter-disciplinary exhibit. As one visitor put it, "I wouldn't have believed that any one exhibition could be so enlightening and so entertaining, appealing on so many levels. My five-year-old daughter enjoyed it every bit as much as I did. It succeeded completely in engaging us both totally, though in quite different ways."[9]

Despite their surface differences, these three humanities participatory exhibits have the same underlying commitment as their scientific counterparts to engage visitors in the design and execution of their own learning process.

Participatory exhibits are coming of age, and they are here to stay. Increasingly, scientific research into museum learning indicates a need and a demand for greater visitor interaction with artifacts. Participatory exhibits are demonstrating they can successfully present artifacts and concepts for enriched museum learning. As they continue to mature and expand into other disciplines, they may be expected to validate Samuel Johnson's apt observation—"Curiosity is one of the permanent and certain characteristics of a vigorous mind"—by providing new ways in which to satisfy man's inherent curiosity and innate desire to learn.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 123–124, June 1986

Facts and Consequences: A Mandate for Science and Technology Centers

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Although science and technology centers represent the very latest type of museum, their lineage stretches back to the beginnings of modern museums. In fact, in 1675 the German philosopher and mathematician Gottfried von Leibnitz suggested a museum "of machines that would entertain the public with magic lanterns, artificial meteors and all sorts of optical wonders . . . with demonstrations of water, air and vacuum." The spirit and design of science centers can easily be traced back through the "discovery" museums. The Exploratorium in San Francisco was inspired by the Palais de la Découverte in Paris with its "animated textbook" approach and the early demonstrations and exhibits of the Deutsches Museum in Munich. Yet there are significant differences between the "new" science centers and the "old" science museums: science centers are more than collections of objects and their programs are directed to the general public. Modern science and technology centers take as their objectives the explication of science to the public, the improvement of science education in the schools, and the encouragement of young people to enter careers in science and industry.

The Association of Science-Technology Centers (ASTC), an organization of 200 institutions, has been instrumental in giving direction to the phenomenal growth of science centers in the United States and abroad by offering conferences, publications, and advice. "Junior Leagues, parents, educators, and business leaders—very concerned about the need for greater science literacy among children and adults—contact us," Bonnie VanDorn, Executive Director of ASTC, explains. "Determined to start a hands-on science center in their community, they ask for help in developing rewarding informal learning opportunities for families and in coordinating with their school system." Science and technology centers, both established and fledgling, typically espouse an explicitly democratic mission, which finds expression in strong links with school science curriculum and with local business and industry. Whether conventional or experimental, public programming is closely tied to community interests. Traditional courses and demonstrations in electricity, astronomy and biology have proliferated, while at Discovery Place, in Charlotte, North Carolina, unusual living history reenactments of famous scientists at work in period settings, as well as a futuristic encounter with robot-assisted demonstrations of basic scientific principles, are being staged.

Science centers, with all their ingenuity, embody some powerful ambiguities. Dramatic popular entertainment techniques hold the attention of audiences, especially family visitors. In the fun of hands-on exhibits, however, the scientific principles the exhibit seeks to teach may be lost. But perhaps the most important dilemma arises from the presentation of science and technology as if value-free. Science centers are exponents of the traditional American belief that our future can be made better through the application of scientific knowledge to human problems. But what about the hidden, broader outcomes of technology? Science can produce monsters, like radioactive waste and acid rain. More science centers need to discharge their obligation to teach the public both facts and consequences, a mandate that may conflict with the priorities of corporate sponsors.

Attendance at science centers continues to rise (roughly 150 million visitors annually); several new ones open each year and they are rapidly spreading around the world. According to VanDorn, "Half of ASTC's member institutions are under 20 years old. In 1982, we had to establish a new category of membership—Developing—for centers in the planning stage." Visitors come to find a unique combination of information and experience that stimulates the imagination and educates for the future. The challenge of science and technology centers is to present technology and its consequences to the public through exhibits and programs that are accurate, engaging, and socially responsible.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 125–130, June 1986

Interpreting the Past in the Present

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People are often under the mistaken impression that history is about specific dates and other obscure facts. Their high school experience of history may have consisted of nothing more than memorizing. While the fact that George Washington did die in 1799 is correct, the significant questions of history are not really answered, or even approached, by knowing that fact. Rather, history is studying such questions as: What meaning did his life have to his contemporaries? Did his death have symbolic meaning to them? What meaning does George Washington's life and death have for us today? In a museum, historians and curators study artifacts, documents, recordings, and other visual records to develop interpretations of the past that both reflect the preponderance of "facts" about the past and speak meaningfully to people in the present.

Old exhibitions, just like old textbooks, consequently require change and revision. In 1964, the National Museum of History and Technology opened as the newest Smithsonian Institution museum. The HALL OF EVERYDAY LIFE IN THE AMERICAN PAST (HELAP) was one of its inaugural exhibitions, examining domestic life and material culture among "middle-class" Euro-Americans in the seventeenth, eighteenth and nineteenth centuries. At its apogée, HELAP hall was considered innovative—combining a large number of period rooms with objects in cases, telling one continuous story throughout the earliest years of American history. But in 1983, the old HELAP hall was dismantled to make way for a new, interpretive hall called AFTER THE REVOLUTION: EVERYDAY LIFE IN AMERICA 1780–1800 (opened in November 1985) (See Figure 1). AFTER THE REVOLUTION retains a similar accent on material culture and everyday life, along with the larger purpose of including the new scholarship and historical perspectives that had emerged in the 25 years since the planning of the original hall. In a sense, the 1780s and 1790s have not changed, but the newly renamed National Museum of American History has just spent hundreds of thousands of dollars and undergone five years of planning to change its public interpretation of that era. This intensive effort has afforded many opportunities to reflect upon the specific problems and pressures inherent in creating history exhibitions.

Museum professionals know that history exhibitions are interpretations of the past and, in that limited sense, fictive. Vir-

Fig. 1.

tually all that a visitor sees in an exhibition is the product of years of conscious deliberation—often adversarial—to come up with a set of historical conclusions, a narrative line, a specific number and range of objects, and finally a visually-compelling design and execution. An exhibition should be thought of as a setting for some highly dramatic objects and information. Sensory stimuli of all kinds—colors, light levels, sound, as well as the style of the installation design, the beauty or particularities of specific objects—all play some role in attracting and holding attention.

Yet too few museum visitors ask themselves these basic questions: What objects and themes have been selected for this exhibition? What has been left out? What is the museum trying to say? The visitor should understand that what he or she is seeing is an interpretation, an argument, a point of view about the past. It is not the "truth," but rather a set of arguments, organized within a narrative structure, and presented in a completely calculated manner, reflecting all the choices made from the first moment to the last during the development of the exhibition. Too few museums are willing to expose this process of decision-making directly to the public. Indeed, many of the particular factors that went into a specific decision might require an entire exhibition or film to explain fully. Further, most visitors—drawn to the historical material itself—may not even be interested in how the museum does its business. However, "de-mystifying" exhibit-making is a prerequisite for helping visitors ask questions about the past as presented in museums.

The first step in the "de-mystification" process is to recognize that the exhibition is little understood as a unique form of cultural discourse. Compared to other expressive endeavors, there is scant critical material on the distinctive features of museum exhibitions. But certain characteristics make exhibitions different from other media as well as make the history exhibition different from other kinds of exhibitions. Unlike film, exhibitions are interactive (museum visitors walk, talk, and participate). Unlike the theater, exhibitions do not have a captive audience (museum visitors can pick what they choose to read and see). Unlike the scholarly book or article, an exhibition is non-linear and usually non-progressive (one third of all visitors enter an exhibition from the exit, regardless of signs). Unlike printed media, an exhibition has spatial, visual, and sequential elements in all dimensions (museum visitors travel through the exhibition environment in real time and space). Most important, museums have the "real things," not just images or descriptions of them; visitors' expectations, perceptions, and experiences are strongly colored by an explicit faith in the authenticity of museum objects.

Museums are often deliberately "temples to culture." Visitors approach them as they would religious shrines, viewing the objects entombed therein as pieces of the true cross. Many traditional marble museums were designed to reinforce this attitude of reverence, giving the museum community an important kind of cultural authority. Moreover, exhibitions have no "authors." Unlike a book that has someone's name on the front, few museums name exactly who did what in a particular exhibition. Of course, an exhibition is a more collaborative project than any book. Historians, curators, collections managers, conservators, designers, fabricators and other skilled artisans, as well as educators contribute to the production of an exhibition. In large exhibitions, scores, sometimes hundreds, of such people are needed. It can be extremely difficult to *establish* authorship. Who exactly wrote which section of labelling? Did the same person do the documentary, artifactual and graphics research? Who should receive the credit or blame for the final product? Further, exhibitions can outlive the individuals who created them. Who then is responsible? The original "author" or those individuals now caring for that collection, hall or museum? Since there are no easy answers to such questions many museums avoid even raising them. However, confronting issues of authorship, structural design, and visitor expectation is essential for understanding the setting in which exhibit-making and viewing takes place.

Yet even within a similar context, all exhibitions are not the same. The art or science exhibition offers few parallels for fully experiencing a history exhibition. Painting, sculpture, photography, and all the other art forms, including performance arts, are clearly the products of an actively self-conscious mind at work to create an aesthetic object or a particular statement. In that sense, art objects are meant to speak directly to the viewer. Art museums often define their role as the development of connoisseurship, the informed appreciation of the art object for its intrinsic excellence or quality; art museum exhibitions are thus designed to encourage the act of looking. But historical artifacts, rarely produced explicitly to "communicate," are ordinarily the mundane objects of the material culture of everyday life; aesthetic appreciation is of secondary importance.

A teacup is just a teacup unless a label indicates that George Washington owned it. This knowledge may place the cup in a different light, but a label was required to confer the additional level of meaning. In history museums, humble, mass-produced objects as well as unique and precious *objets* must be interpreted. And the significance of an egg timer—a prime example of increasing mechanization in households at the turn of the twentieth century, emblematic of a major movement toward "science in the home"—simply is not evident without a context. Historical artifacts were not made to speak directly; only the antiquarian, curator, or historian with prior knowledge is likely to "hear" their cryptic messages. The creation of the most effective context for understanding is therefore the chief objective in developing a history exhibition.

Science and history museums, unlike art museums, share a subject-matter orientation. Science museums endeavor to teach the public about science and the scientific perspective and, at their best, to draw connections between science and the world at large; history museums endeavor to teach about history and the historical perspective. Science and history museums differ, however, because their disciplines have different standards for evidence and proof.

Scientists study the world of matter and abstract relations or natural laws that seem upon observation to undergird it. Although a number of historians of science believe that the profession and practice of science are highly political and influenced by all manner of cultural obsessions, most scientists believe that they are seeking "basic truths" that can be demonstrated in an experimentally observable way. By contrast, history is the study of earlier societies and past events. Historians know that the methods of history are quite different from the methods of science. History is not susceptible to the replicable demonstration associated with scientific subject matter. Because history is the study of earlier peoples and times, it cannot be recreated in the present upon demand. By definition, history is the analysis and interpretation of something which was only "true" once, in the past. Evidence and proof must be based not on replicability but rather on a carefully argued synthesis of a wide variety of period source materials.

Consequently, historians are often pleased to discover a "mediated truth," filtered not only through their own cultural consciousnesses, but also through the available remaining evidence. Gravity cannot be "lost"—it can always be demonstrated anew to the young student and the curious adult. But historical evidence like letters can be destroyed by fire, furniture can be irretrievably untraceable, certain information may always be unknown. History can be viewed as a search for truth, but the outcome is never truth, only argument, always interpretation.

Like all history exhibitions, AFTER THE REVOLUTION: EVERYDAY LIFE IN AMERICA 1780–1800 was profoundly affected by the state of scholarly research, the availability of artifacts, and the constraints of the exhibition as a mode of communication. Its predecessor, the HALL OF EVERYDAY LIFE IN THE AMERICAN PAST, had once encompassed the best of scholarship, artifacts, and exhibit design nearly a quarter century ago. Not about great events nor famous people, the HELAP hall gave center stage to material culture and everyday life. But its examination of the lives of "middle-class" Americans spanned 300 years, implying that the experience of early-settling, Anglo-American Protestants (with a smattering of German-Americans and other western European groups) stood for the history of all Americans during the sweep of American history. The HELAP hall consequently conveyed an archetypical, nostalgic impression of the American past devoid of change and conflict. Over time, the exhibition began both to look out of date (the colors were out of fashion; the period rooms seemed quaint; the lack of lively events compared poorly with living history, folk festivals, and artisan demonstrations) as well as to generate criticism of its basic assumptions among scholars and the general public alike.

Although the museum staff within the Department of Cultural History began talking about doing a new hall in the mid-1970s, the enormous impetus necessary to drive a project of this magnitude awaited the arrival of a new director, Roger Kennedy, at the National Museum of American History in 1979. By then, a body of scholarship had accumulated to lay waste to many of the guiding principles of the HELAP hall. Post-war consensus historiography—which had emphasized intellectual and political history over everyday life, which had minimized all conflict, and which celebrated the economic structure of the "middle class" (with the concomitant notion that the "middle class" stood for everyone)—was attacked by a new generation of historians, who saw class, race, and gender relationships of all kinds, as well as economic and political conflicts, as the primary sources of historical change. Further, the "new social historians" were committed to uncovering the history of the masses of people who had not left extensive personal documents and family records, but whose lives, individually and in aggregate, were revealed by birth and death rates, marriage records, census lists, tax information, and military pension files. These new historians sought to chart the seismic changes in behavior patterns, economic relations, and social life—often barely perceptible to the participants but evident to later researchers—that reflect the lives of all people.

Scholarship about the Revolutionary Era itself altered the static, balanced, and homogeneous world of order that 1950s and 1960s consensus historians had painted. Social historians saw a world of great cultural diversity, seething with political and social conflicts—like slavery—and in rapid economic change. The new "telling of the tale" of the first American citizens needed to acknowledge the stories of both Native Americans (important far beyond their relatively small percentage of the total population) and African-Americans (some 20% of the nearly four million people counted in the 1790 Census).[1] A new exhibition would have to make clear that the United States—caught up in a world-wide system of goods and exchange that included not only Europe, but also the Caribbean, Africa, India, and China—was not independent and self-contained.

Thus many of the historical principles that served to formulate the HELAP hall were explicitly reversed in the new exhibition. Yet more than 600 of the artifacts as well as four of the many period rooms installed in the original HELAP hall are incorporated in the 1250 objects in AFTER THE REVOLUTION, since both exhibitions share a fundamental concern with the stuff of everyday life—material culture. The HELAP hall had accurately reflected the bulk of the appropriate collections for this period held by the then National Museum of History and Technology. The new research, however, dictated locating and selecting artifacts that would give tangible and telling expression to its abstract arguments. But artifact selection—the most critical aspect of exhibition preparation—is predicated on artifact availability. The dearth of eighteenth-century African-American artifacts in the Smithsonian collections, the housing of Native American objects as ethnographic material in the Smithsonian's National Museum of Natural History, the overlooking of the material culture of virtually all poor people (more than 60% of the cultural history collections of the National Museum of American History documents the tastes and lifestyles of the upper 10% of the Euro-American population throughout American history) hampered ready translation of history scholarship into history exhibition.

Nineteenth-century collectors, preferring objects associated with the rich and famous, not surprisingly failed to anticipate today's recognition of artisan artifacts as valuable and culturally significant. Eighteenth-century painters, engravers, and limners recorded harbor scenes, quiet parks and stately buildings or portraits rather than the "snapshots" of everyday life that would be appreciated today. Given these powerful strictures on artifact availability, to weave together a coherent narrative in AFTER THE REVOLUTION of the new scholarship in a visually-pleasing design, loan objects, graphics (where no objects existed) and reproductions (clearly identified as such) were assembled for exhibition.

Another goal was to make the process of historical research and proof more visible to the visitor. In AFTER THE REVOLUTION, whenever possible, the "guts" of the historical endeavor are included in the labelling and in the overall context. A section on Everyday Life in the Chesapeake includes information on how historical archaeology contributes to knowledge of African-American culture. The Connecticut River Valley Parlor, set in 1784 as if an inventory were being taken, gives an opportunity to talk about how historians know what they know. On occasion, labels mention where information falls short, when historians disagree about a certain fact, or if an oral tradition is in conflict with other documentary evidence.

The task of historians generally and history exhibitions in particular is to interpret the past in ways that are meaningful to people in the present. Of necessity, that interpretation translates the detailed and sometimes obscure findings of historians and curators into interesting bits of labeling and dramatically-organized objects and graphics. This interpretation—this translation—requires metaphor, which lets certain concepts, objects, images, or sounds stand for something else. In the process of developing the most elegant balance, some information is weighted more heavily. Each age highlights the information of most interest to itself, thereby marking its own time and place in history—vaguely discernible to contemporaries but clearly evident to those who come later. Since all ideas can be viewed as heresy, verity or passé at various moments in time, so particular metaphors become dated as the setting in which they were developed shifts. AFTER THE REVOLUTION is as subject to these fluctuations in esteem as the

HELAP hall or any history exhibition—indeed all historical argument.

Recapturing the past, even the recent past, is never simple. Figuring out what happened more than two hundred years ago is considerably more complex. Some facts are forgotten, others disputed, and a few invented. The past itself never changes; memory and interpretation do. Each generation asks "history" to serve different purposes, looking to the past in light of the issues and controversies that give meaning and definition to its present. AFTER THE REVOLUTION: EVERYDAY LIFE IN AMERICA 1780–1800 reveals late twentieth century concerns about diversity and conflict as well as eighteenth century hopes, challenges, and struggles. This new installation at the National Museum of American history mirrors both the past and the present. In a real sense, like all history museum exhibitions, it inevitably—and principally—tells *our* story.[2]

Notes:

1. First American Census, 1790. The total population of the United States was 3,900,000, including 700,000 enslaved and 50,000 free African-Americans. National origin breakdown: 48.0% English, 19.4% African, 8.5% Scots-Irish, 7.2% German, 4.7% Irish, 4.3% Scottish, 3.5% Welsh, 2.5% Dutch, 1.7% French, and 2% Swedish. The best scholarly estimates of Native Americans suggest that there were about 100,000 east of the Mississippi and 500,000 west of it (or less than 2.5% of the U.S. population).
2. Paragraph is a paraphrasing of one section of scripting in an audiovisual program titled THE PAST IN YOUR FUTURE, produced for the Life in America Project in 1982–83 by Shomer Zwelling and Avi Decter of the Center for History Now.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 131–132, June 1986

Representing Cultural Diversity: A Responsibility of History Museums

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The Afro-American Communities Project was established in 1981 to study free black urban communities of the antebellum period. Funded by the Ford Foundation, the George Washington University, the National Endowment for the Humanities, and the Smithsonian Institution and housed by the National Museum of American History, the Communities Project is directed by Dr. James O. Horton, Associate Professor of American History and Civilization at the George Washington University.

Using the methods and materials available to social historians, Dr. Horton and his staff are analyzing the social, political, and economic structure of free black communities from the Revolutionary period up to the Civil War in Boston, Buffalo, Chicago, Cincinnati, Detroit, New York, Oberlin, Philadelphia, Pittsburgh, and San Francisco. The Communities Project has compiled over the course of four years the most extensive data base ever assembled on free blacks in the urban North.

Initially, researchers studied the Census records of 1850 and 1860, the Veteran Administration's military description books for the Civil War, and nineteenth-century newspapers and personal papers. More recently, the research staff has consulted nineteenth-century probate records, including wills and inventories, to glean further information about economic conditions as well as clues about family and community associations. The geographic logging of signers of wills, their beneficiaries and witnesses on antebellum city maps may make possible the reconstruction of neighborhood networks.

The relationship between the Communities Project and its host has been mutually advantageous, according to Dr. Horton. The Smithsonian's sponsorship has conferred welcome visibility and prestige upon the Communities Project, while the Communities Project enhances the visibility and popularity of the Smithsonian among the black community. The Smithsonian setting also has promoted healthy cross-pollination of the expertise of project and museum staff. By rubbing shoulders with specialists in material culture on a routine basis, Dr. Horton has become acquainted with primary sources that he might previously have overlooked. The material culture experts encouraged the current intensive focus on probate records and suggested the investigation of modes of dress, the latter study revealing that clothes served as a "common badge of circumstance" for indentured whites and indentured or enslaved blacks alike during the eighteenth century.

With the enrichment of his own scholarly endeavors through heightened appreciation for material culture as evidence, Dr. Horton advocates that all written treatments of American history take the artifactual record into greater account. In turn, Dr. Horton has been called upon to deliver lectures to museum docents, to assist in the preparation of educational kits for school children, and to review and comment on exhibition scripts. The Communities Project's research has contributed to the exhibition, AFTER THE REVOLUTION, which exemplifies Dr. Horton's view that museums have an obligation to acknowledge "the warts on the American complexion. History museums may find it more comfortable to concentrate on the Frederick Douglasses of this society, but museums have a public responsibility to present information as well on non-elite blacks."

By offering balanced, accurate interpretations of our country's past, the history museum can be of great service in shaping America's future. Through truthful presentations about the past, museums can contribute to lowering the barriers which currently segment our society. The ultimate goal of the Afro-American Communities Project and numerous other social history projects is to ensure that the diversity found in American society throughout our history is adequately represented within the museum's walls.

Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 133–138, June 1986

"BARKING DOGS" and the Visitor: Museum Evaluation and the Search for Effective Exhibits

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The following is an edited version of an interview with Harris H. Shettel. Mr. Shettel has been active in the study of museum exhibit effectiveness for more than 20 years and is a recognized expert in the field. Since 1962 he has carried out numerous evaluation studies for museums and exhibitions in the United States, Europe, Asia, and South America and has published widely on the subject. He is currently conducting a survey for the African-American Museums Association to assess the status of black museums in the United States. He lives in Washington, D.C.

What led you to believe that a need for evaluation existed in the museum world, and what special perspective did you think you could bring to bear?

I would *like* to say that, as a student, I studied and read about museums and decided to go into exhibit evaluation as an early career choice, but the fact of the matter is that I stumbled into the field quite by chance. A telephone call came into the American Institutes for Research office (then in Pittsburgh) from an expert in trade fairs and expositions who was at the time employed by the National Science Foundation. He was interested in finding out if people who worked in the area of audiovisual research and development would have anything to offer by way of research findings that would be applicable to exhibit effectiveness for the museum and trade show community.

The call was routed to me because I had been engaged in media research for a number of years. As we talked, I began to wonder whether anyone had actually studied the development and impact of exhibits from the perspective of the educator or the communicator.

Well, as a result of that call, I began to look at the museum literature to see what had been done. While I found a few well-designed empirical studies in my review, I found many more apparently unsupported assertions about what was or was not a characteristic of a "good" or "bad" exhibit. What did those who made such assertions really know? Had they discovered through trial and error and years of experience the essence of exhibit effectiveness? Such musings led me to write my first request for funds.

What I proposed was to try to find out whether the people who wrote about, designed, and/or bought exhibits—museum directors, curators, exhibit designers—"really knew" what a good exhibit was. I began to go through the literature systematically, pulling out all the phrases used to describe exhibit effectiveness, like "A good exhibit should have coherent unity."

Based on such statements, I developed a 36-item rating scale for exhibits. I gave this scale to "exhibit experts" and asked them to rate a given exhibit. My thesis was that if everyone tended to rate an exhibit the same way, that would suggest some agreement about the presence or absence of those qualities that were claimed to constitute a successful exhibit. After all, reliability must precede validity. Without a fairly high level of agreement (reliability), there would be no point in asking the much more difficult question, "Do these characteristics actually relate to the objectively measured effectiveness of the exhibit as a communicator to the visitor?"

And how did your results look?

As it turned out, there was almost no agreement. Exhibit expert "A" would say that an exhibit had all of the fine qualities listed in the rating scale, and exhibit expert "B," looking at the same exhibit, would say that it had very few of those qualities. I am oversimplifying a bit here, but the basic results strongly suggested that the experts didn't appear to know what a "good" exhibit should look like or should have. That convinced me that there was a need to sort out what those variables are that lead to exhibits that communicate successfully to the public and suggested to me that my experience as a training developer and media researcher could possibly bring a useful perspective to such an effort.

I want to point our before we get too far along that there were a number of people who took a similar approach to museum studies at about the same time. There seemed to be a surge of interest in museum research of all kinds in the mid-1960s, as reflected in the increase in published studies at that time. I did not know it then, but I was not totally alone in my interest in the educational potential of museums.

How do you "diagnose" a given exhibit's evaluative characteristics and needs?

First of all, I find it useful to divide exhibits into three basic categories—the aesthetic, the intrinsically interesting, and the didactic or educational. The aesthetic exhibit has as its primary purpose the display of beautiful things. A Ming vase or a painting by Titian is displayed so visitors can be in the presence of "beauty." In most cases, no specific educational claims are made; it is simply hoped that visitors will have an aesthetically pleasing and rewarding experience. The second category, intrinsic interest, includes displays of objects that have significance to a sizable portion of the population by virtue of their history or context. A piece of rock from the moon possesses (or did) such intrinsic interest, although it looks like an ordinary rock. Not so long ago people waited in lines that wrapped around the block to see this small piece of the moon, and I was one of them. The First Ladies' inaugural gowns, the Wright Brothers' flyer, and the Hope Diamond are all examples of this type of intrinsically interesting exhibit.

The didactic or educational exhibit has as its objectives conveying information to, changing the attitudes of, and/or provoking interest in the casual visitor. A didactic exhibit, I believe, ought to be able to convey what its originator intended it to convey and be subject to the same type of analysis that is applicable to other kinds of educational materials.

I should quickly point out that I do not consider these three categories to be mutually exclusive or contradictory. In fact, some of the most effective exhibits I have worked with had all three elements present. But I do find the distinction useful because it avoids the confusion and frustration that occurs when evaluation concepts are applied to exhibits that really have no clear educational intent.

So, to get back to your question, the diagnosis of a didactic exhibit's effectiveness is based on the extent to which it can convey its intended messages to its intended audiences. To do so it must do three things—attract that audience, hold it, and communicate with it. A weakness in any one of these areas reflects on the others. A complete diagnosis requires that we obtain information about all three of these factors—and this is what we try to do.

What, in your view, is the ideal course of development for a museum evaluation project?

I prefer to be involved as early as possible in the exhibit development process, preferably in the conceptualization of the exhibit. To me, evaluation is a process, not a product; it is not something to be "tacked on" after an exhibit is finished. Evaluation is a way of thinking, and that way of thinking ought to be introduced when people first begin to have the germ of an idea for an exhibit. The evaluator at that point might be called more of a planner. He or she is not evaluating per se, but introducing notions like defining objectives and deciding what the intended audience is like (age, sex, education, etc.). These critical factors ought to be determined in the early design stages of an exhibit, not after it is built and put on the floor.

Later the evaluator will consider and offer guidance on the selection and placement of objects, the content and reading level of labels, and the selection of media (films, models, interactive computers, visitor-controlled videodisc presentations, etc.).

As the exhibit continues to evolve, the evaluator continues to remind the developers and designers of their original intent and of the audience they are trying to reach. In short, the evaluator might be considered as the "ombudsman" for the eventual visitor.

Toward the end of this process, when the design is beginning to firm up and the objects and labels and media are initially decided upon, I strongly recommend constructing a mock-up of the exhibit for purposes of pre-validation and revision. Such a mock-up can have labels that are typed, not silk-screened, and objects placed in approximate positions, not mounted permanently. If needed, working models can be built in rough form, but they should be finished well enough to give an idea of how they will perform in the actual exhibit. The point is, we want to be able to change those things that are not performing as intended.

Incidentally, the first mock-up study I did in 1967 (and I believe it was the first one that was ever done) was done backwards. I had evaluated in great detail a large exhibit that had many models and objects. I knew what parts were effective in meeting the exhibit's educational objectives and what parts were not so effective. I then took color photographs of the objects in the exhibit, made copies of all the labels, and mounted this two-dimensional exhibit on the walls of our AIR office in Pittsburgh. I brought in people who were comparable to the visitors I had already tested in the real exhibit and asked then to tour the mock-up exhibit.

I found that, while the mock-up was not quite as effective overall as the actual exhibit, the profile of the results from both studies matched each other almost perfectly: where the real exhibit was weak, the mock-up was weak; where the real exhibit was confusing, the mock-up was confusing. I thought at that time, and still do, that the mock-up validation of exhibits ought to be a requirement of every exhibit development effort.

Are there any limitations of mock-up studies?

Based on the many mock-up studies that have now been done, I believe that well-developed mock-ups have, in surrogate form, the basic educational characteristics of the finished exhibit. They are not, however, effective surrogates for measuring the attracting and holding power of such exhibits. As I said earlier, exhibits, to be effective, must also attract and hold the attention of visitors. If one can't get people to come over to the exhibit, then one can't inform them. If people come over and glance but don't stay to look and read or listen, then they aren't going to learn very much either. Mock-ups, as a general rule, do not have good attracting or holding power. Because of this limitation in mock-ups, we usually test them under more controlled conditions, where visitors are asked to look at them so that we can get an adequate and representative sample. I have also tested mock-ups in settings outside the museum where an even broader cross-section of the population may be found (for example, lobbies of buildings, public libraries, etc.). Mock-up validation studies are becoming more accepted, and some museums, like the British Musuem of Natural History, do them routinely.

Having looked at the results of the mock-up study, one can then consider making the necessary changes in the exhibit. One can correct labels that don't make sense to the visitor, move objects that are placed ineffectively, remove objects that only add clutter, rework a visitor participation idea that "bombed," and so on and so forth. One can also retest the exhibit to see if the changes made a difference. When we put the finished exhibit out on the floor, we may want to carry out other and more traditional evaluation studies, such as summative evaluations (if we can afford them) and tracking studies. But even if we don't do a summative study, we have some reasonable assurance that our exhibit is effective. If I had to make a choice, I would do the mock-up rather than the summative. I would also do a tracking study, however, after the exhibit is installed. They are very useful and revealing.

What are tracking studies, and how do they work?

Tracking studies are essentially a form of refined snooping. Very detailed diagrams of every part of the exhibit or exhibit area are developed. Then we literally (but unobtrusively) follow people through the exhibit and document carefully where they go and in what order, how much time they spend and what they do at each exhibit or each part of the exhibit (depending on the level of detail desired).

Tracking studies provide us with a great deal of information about the attracting and holding power of an exhibit. Some exhibits or exhibit areas have poor attracting power but are able to hold the visitor very well. Other exhibits have very high attracting power but poor holding power. Sound, for example, has great attracting power. I've often said that I will guarantee the 100 percent attracting power of any exhibit if I am permitted to put barking dogs in it. Anyone who is within earshot of barking dogs would go over to find out what's going on, although once they get there, they may or may not stay. Lights and colors are more traditional methods used in an effort to attract visitors. But there is a drawback to making everything flashy. If there were barking dogs in every exhibit, the novelty would soon wear off! One has to think of other more intrinsic ways to attract and hold the attention of visitors.

But I digress. Now that we have carried out our tracking study, we know where people go, how long they spend in each site or area within the exhibit, and what they do—whether they talk, point, laugh, read, or glance. The evaluator documents these data for the designers and the curator and may recommend changes where there are problems. Even though the exhibit is finished, one can still revise the lighting scheme, or move objects and even cases around, or change the traffic pattern through the exhibit. One can even experiment to see what works best. A number of museums, by the way, routinely carry out tracking studies. They are relatively inexpensive and persons on the museum staff can be trained to do them in a short time.

How do you conclude an evaluation study?

We usually prepare a final evaluation

report that assesses both visitor learning, changes in attitude, or interest and the results of the tracking studies. We try to be as specific as possible, relating the findings to the original intent of the exhibit. We also make recommendations for changes where they are possible. "Dos" and "don'ts" for future work are pointed out when appropriate. I also like to review the entire exhibit development process, not just the evaluation results. Oral briefings with the museum staff are always helpful. The emphasis throughout the process is on the positive; we try to emphasize the half of the glass of water that is full (and how to make it fuller), not the half that is empty.

Unfortunately, I have seen such reports more often than not sit on the shelf of the museum director's office, having had no visible impact on subsequent exhibit development activities. It is for this reason, as I said earlier, that I believe that an evaluator ought to be a member of the development team and that he or she be involved in the entire development process, not only of exhibits, but of educational programs as well. Of course, it may not be feasible to do a mock-up of an educational program, although. . . .

Programs could be developed and tested in pilot form.

Exactly. I've been involved in the training world for more than 30 years, and I still pilot-test all of my training courses and materials. I am not able to write a training course that will work as well as it could the first time. There is always something wrong with it. I make mistakes because I still don't (and never will) know enough about human behavior to predict everything that will happen when someone uses one of these programs. What I think is perfectly clear and intelligible, someone else may find confusing and obscure. I have to revise; and I revise willingly, as a natural part of the development process. When museums can accept evaluation as a helpful tool—as an aid in their work, rather than as a report card—evaluation will really begin to play a major role.

It does seem that there is a persistent belief that "evaluation" means destructive criticism.

Yes, it's seen as a negative reflection on the wisdom and perspicacity of the people responsible for the exhibit or program, which is really too bad. Designers are especially sensitive to findings that show that visitors are not always as entranced with their exhibits as they "ought" to be. A number of us have tried to think of a word that does not convey the pejorative implications of "evaluation," but we haven't come up with anything yet.

What other obstacles, in your view, make it difficult for museum professionals to accept—and seek out—evaluation?

What I've been talking about up to now could all be called formal evaluation. However, there is another sense in which the word "evaluation" is used. I've heard museum people say, "Well, of course I evaluate. I review and approve the design, the label copy, the selection of objects, etc. I go out on the floor and watch people as they look at the exhibit. I even talk to some of them. I'm evaluating all the time." But that's not what I'm talking about. That species of self-assessment and professional judgment—informal evaluation—is used by all of us in our work every day, and it should be. But, it leaves out the crucial factor—objectivity—that distinguishes formal from informal evaluation. I submit—and I have a lot of evidence to support this statement—that there is a fundamental difference between what the individual who participates in the exhibit development process thinks about the exhibit and the way in which that exhibit is perceived and received by visitors.

As one example out of many I could cite, I recently helped a small local history museum set up a tracking study in a new wing of the museum, where a large (and impressive looking) exhibition had been installed. It cost a bundle. The director of the museum, a very savvy person, was proud of it. Other exhibit people liked it. The designers liked it. But my director friend was shocked to his professional toes ("Shattered our views of our audience!") to find out that the typical casual visitor spent only a few minutes in this area.

There are two ways to deal with this kind of finding—ignore it and don't do any more tracking studies, or try to remedy the problem. He is choosing the latter course of action, and I dare say, he will do more studies of that type in the future. He will also think harder about the design and layout of his next exhibit. He may even do a mock-up study!

So, starting the process of formal evaluation, as we have discussed it briefly here, definitely takes courage. I believe, however, that when enough museum professionals accept evaluation as a normal evolutionary process, they will see that it really isn't as painful as they thought it would be. In any case, we owe it to ourselves to be as accountable as we can for the money we spend and for the effectiveness of our exhibits—and we certainly owe it to our visitors!

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Journal of the Washington Academy of Sciences,
Volume 76, Number 2, Pages 138–140, June 1986

Contributors

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VOLUME 76
Number 3
September, 1986

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly
at Washington, D.C.

CHESAPEAKE BAY
A CASE STUDY OF ECOLOGICAL CHANGE THROUGH HISTORY

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Washington Academy of Sciences

Founded in 1898

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Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Page i, September 1986

Editors' Introduction

James P. Thomas
Rosemary K. Monahan

NOAA Estuarine Programs Office, Washington, D.C.

In this era of ever-increasing specialization, the symposium recorded in these pages is unusual. On December 5, 1985, experts from a variety of disciplines met to exchange their views on ecological change through history, using the Chesapeake Bay as a case example. Dr. Kent Mountford of the U.S. Environmental Protection Agency provided much of the driving force behind bringing these experts together at this symposium, which was sponsored by the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, and the U.S. Fish and Wildlife Service.

In his directive to the speakers, Dr. Mountford pointed out that mankind can and must learn from the past if we are to protect and restore our natural resources for future generations. This task is becoming increasingly urgent as we see our coastlines and living resources disappearing or becoming contaminated. Much can be gained by a careful examination of what history has to teach us, and the authors contained in this volume have provided us with many valuable lessons.

The broad range of disciplines represented at the symposium includes archaeology, history, paleocology, and terrestrial and marine science. The blend of topics addressed by these authors provides a unique, long-term perspective on changes in the Chesapeake—both those caused by natural forces as well as those caused by humans. Although the changes and trends discussed are specific to the Chesapeake, the insights gained should be applicable to many of the nation's estuaries. Now it is up to us as responsible citizens to learn from the lessons of the past and act to ensure that our natural resources will be protected for generations to come.

Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 141–145, September 1986

Ecological Change through History—an Introduction

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I took some time before this symposium to consider how I might insightfully introduce such a diverse suite of subjects. My conclusion is, first, to emphasize how important this kind of interchange can be among very different disciplines, not only to each of us as scientists, but to those of us who are managers working to restore damaged ecosystems. The lessons we can learn from bringing together at one symposium the diverse group of experts recorded here include the following.

- The application of new tools from a previously unfamiliar field can result in quantum leaps in understanding.
- The very long term perspective we discuss here can help greatly in understanding the magnitude of change that ecosystems, in this case Chesapeake Bay, have undergone.
- Understanding the kinds of cyclic long- and short-term events that have occurred in the past can help us in the management struggle to decide how far back we are likely to be able to bring the Bay from its currently impaired state.

My current job is to coordinate, for the Environmental Protection Agency (EPA), a monitoring program that covers Chesapeake Bay, this Nation's largest estuary, from the fall line to its confluence with the Atlantic Ocean. The purpose of this program is to look carefully, but with broad vision, at trends in environmental quality and the Bay's living resources, and to determine if either or both show ameliorative results from the expenditure of some $200 million in tax dollars each year.

When we aggregate the EPA wastewater treatment dollars, the commitments of state and local governments, and the moneys Congress has earmarked for Chesapeake Bay, the cash investment is prodigious and we had better be able to demonstrate positive results or our constituents, and their elected representatives, will rapidly lose interest.

At the same time, I have been an environmental scientist for some 21 years and have watched the incredibly complex response estuaries have to the passing seasons, the stunning contrast between drouth of record when, for example, the Potomac flowed at under 19.8 m^3/sec (<700 cfs) and floods with return frequency of a century, when the same river flowed at 7,084 m^3/sec (>250,000 cfs). Consider also the far-reaching effects when a severe winter like 1976 locks up freshwater flow in snow and ice-cover for two months at a time, then releases it in a brief melt period.

Each of these events has had profound effects, sometimes persisting years, even decades, on water quality and living resources in Chesapeake Bay. The principle is unaltered in other habitats as well. How can we hope to elucidate trends in a program where sampling has (at this writing) only gone on nineteen months? Ignore that time scale and consider all the historical data we have. Almost none of the water quality data for this estuary pre-date Dr. Abel Wolman, who summarizes the contributions contained in this symposium volume.

I wonder quite frequently if we would sometimes maximize our information by sitting down with senior investigators like Dr. Wolman, his colleague Dr. Reginald Truitt, or even watermen with long experience, and documenting their perceptions carefully. I've certainly done this to advance my own understanding, but the skills and precautions necessary in this profitable exercise are considerable, as noted by Paula Johnson in her paper "The Worst Oyster Season I've Ever Seen": Collecting and Interpreting Data from Watermen.

In the face of my day-to-day difficulty assessing trend in the estuary, I maintain a few points of very long perspective that help keep me on an even keel. One of those points is a copy of John Smith's "Generall Historie," a facsimile of the original 1629 text. He writes there on the two winters 1607 and 1608:

"In the yeare 1607 was an extraordinary froft in moft of Europe, and this froft was found as extreame in Virginia but the next year, for 8. or 10. days of ill weather, other fourteen days would be as Sommer."

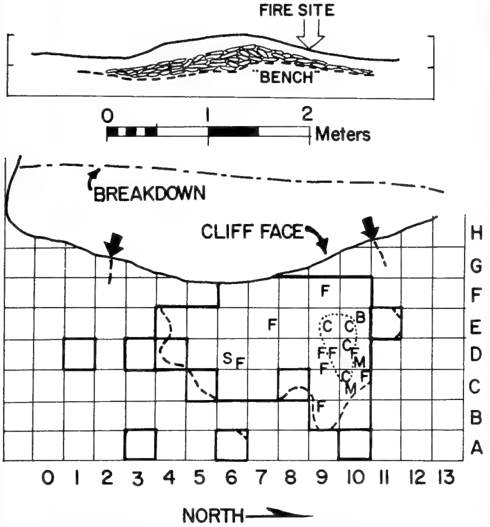
We are, comfortingly, not alone in our perception of environmental variability; in trying to gauge the mean, or describe what one might expect next from nature.

Paula Johnson recounts later in this volume a tale from the great 1950's Patuxent croaker run. It's a tale, that with most of the essentials intact, came to me from Maryland Senator Bernard Fowler over three years ago. Consistency in the basic elements, recounted from independent sources, allows the astute interviewer to sort out fact from embellishment. Where fisheries statistics support the stories, we can begin to home in on what conditions in the past really were.

When you have read Ms. Johnson's account, consider a moment if that was the Chesapeake we should strive to restore, or were we then somewhere along the course of a long-term cycle in specific species abundances that are but dimly understood? Might they reoccur, or are we never to see a fishery like that again?

Henry Miller (Transforming a "Splendid and Delightsome Land": Colonists and Ecological Change in the Chesapeake 1607–1820) will hint at other such cycles. His work offers immense possibilities for extending our perceptions of fisheries use and yield far into the past. The keys to interpreting these data may lie in history and folklore, which in their turn, allow comparison with the record, and cross checking with the participants. L. Eugene Cronin (Chesapeake Fisheries and Resource Stress in the 19th Century) draws from the quite extensive records that developed in the 1800s to help us understand a period when the white man's massive harvest pressures were most brought to bear.

As a result of his voyages of "discovery" (exploration) in 1607–08, John Smith produced a remarkable, accurate map of the Chesapeake that has survived in several published versions. It shows the mouth of the creek where I am privileged to live, which was flanked by two Indian villages—Opament (the apparent site of which was excavated by the Maryland Historical Trust in 1984), and Quomocac, the site of which is probably now preserved on State land. The remains of an encampment site, likely spun off from one of these villages, lay buried in my yard until two years ago



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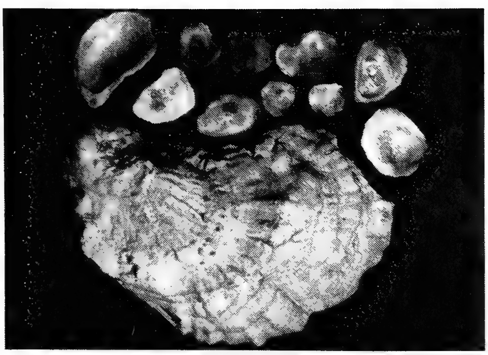

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Fig. 1. A. Site plan of the feature at Osborn Cove, St. Leonard Cr., MD (Lat. 38 deg 28′ 53″ N, Long. 76 deg 24′ O″ W showing quadrats where artifacts were recovered: S = pottery sherds, F = quartz flakes, C = charcoal, M = *Mya arenaria* (softclam) shell, B = fish and mammal bone. B. Oyster shell from the Osborn Cove dig showing abrupt disappearance of the boring sponge *Cliona*, the result of apparent environmental changes in the creek during the late woodland period (750–1650 AD). C. A 15 cm "cove" oyster from the Osborn Cove dig, together with associated spat ranging upwards from 15 mm size. Spatfall is essentially nonexistent on the present-day oyster bed at this site. D. Colonial Maryland tobacco *Nicotiana* sp., collected by Dr. David Krieg in 1698, and preserved in Britain as a botanical specimen (photo by Mountford, with cooperation of Dr. James Reveal, University of Maryland Department of Botany).

when shoreline erosion caused a breakdown of the cliff.

Shoreline erosion is just one of many phenomena on a geological scale that affect us daily. People around the Bay perceive shoreline erosion as a serious problem, but Grace Brush will sharpen our perspective (Geology and Paleoecology of Chesapeake Bay: A Long-Term Monitoring Tool for Management). Erosion has been going on for millenia, and the rates of innundation, rates of retreat, and other records stored in the sediment have told us much about where the Chesapeake has come from and literally at what rate she is making the journey through time.

If one picks through the shell in my frontyard Indian midden, which was occupied some time in the "late woodland" (AD 750–1650), one can find oysters larger than those living today on the same bed offshore. Many of the shells are riddled by a boring sponge, *Cliona,* the presence of which is indicative of higher salinity than we experience in most years today.

In 1979 I wrote to Maryland's Tidewater Administration indicating the lack of oyster set on the oyster-bed that I lease . . . the same bed my Indian predessesors harvested in the 16th century. Tidewater replied that this creek was an acceptable growing habitat but never, in the three decades of my respondent's experience, had this area had any substantial oyster set. I have, in fact seen only three or four spat in eleven years on the creek.

My Indian site, however, was salted with (probably) thousands of spat from the late 1500s. Here is something that has changed, and it is beyond what we can perceive from our own experience. This is where archaeology and modern fisheries biology and management come together in unique combination. Jay Custer will enliven that relationship for us today (Prehistoric Use of the Chesapeake Estuary: A Diachronic Perspective).

I am an ecologist, and when I pick up one of those big oyster shells from 400 years ago I see a growth structure representing seventeen to twenty years of this estuary's history in my hand. Modern sectioning and acetate replication techniques can reveal something about virtually every day in the life of this oyster, even something about predator stress and the oxygen levels the animal experienced. If we could fix a single point in time for this chronology, the rest, like tree rings, would unfold history.

Tree rings bring to mind the Maryland dendrochronological record assembled by H. J. Heikkenen. This has received much less attention than is deserved for a record virtually continuous from the 1500s to the present. I would not be surprised if it could tell us not only about climate, but about some of the changes in forest response we now ascribe to industrial pollution and acidic precipitation.

Ecology and archaeology come together. The potentials for interactions go on; my colleague Jim Reveal at Maryland uncovered hundreds of herbarium sheets in England. These sheets contain original plant material that was gathered in Maryland in the late 1600s. I looked at these plants—the original spindly Indian tobacco and other species now extirpated from the Chesapeake flora—and wondered whether we could use these plants to compare conditions today with those of the 1600s. Perhaps we could examine pollution by using nondestructive elemental tests to measure heavy metal concentrations. In the same archives are algae and molluscs from the 17th century Chesapeake with which no one has worked at this writing.

My colleagues at Martin Marietta Corporation recently used historical records and modern computer modelling techniques to extend probable river flows back a hundred years in several East coast rivers, including some in the Chesapeake. Much can be inferred from records like these about nutrient loading, and the link with older fisheries data sets is obvious.

The series of papers contained in this volume is sufficient only to whet our appetites, and I hope the participants, and you as readers, will revisit the topic and expand on its potential.

I am most encouraged that we can extend our vision back through time in surprising and sophisticated ways to gain a meaningful perspective. I think you, as readers, will find there are exciting possibilities from sharing technology among the several sciences, and that we can define in useful ways what Chesapeake Bay, and other troubled habitats on this planet, were like in the distant past.

Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 146–160, September 1986

Geology and Paleoecology of Chesapeake Bay: A Long-Term Monitoring Tool for Management

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ABSTRACT

A long-term record of selected organisms, parts of organisms, charcoal, and other biological and chemical components preserved in sediments deposited in Chesapeake Bay tributaries is used to reconstruct the history of the estuary, and to compare the effects of natural and anthropogenic factors on the estuarine system. A continuous record of pollen of terrestrial plants, metals, and charcoal spanning 4000 years shows irregular sequences of wet and dry conditions, with the most pronounced wet period ~2500 years ago and the most pronounced dry period ~800 years ago. The magnitude of the climatic change as reflected in the vegetation suggests that, at different periods of time, fresh water flow into the Chesapeake Bay and salinity were substantially different from present conditions. The record of diatoms and seeds of submerged aquatic plants shows the effect of European settlement. Diverse benthic estuarine communities, which occupied the upper estuary some 300 years ago, were converted to predominantly planktonic assemblages as the rapidly expanding human population discharged increasing amounts of sediment, nutrients, and toxics into the tributaries. This paper presents some examples of how the stratigraphic record can be used to trace the history of changes in the estuary and to separate effects of natural events from anthropogenic activity.

Introduction

In designing a management program for an ecosystem, regardless of the objectives, it is important to know how those variations in the environment controlled primarily by nature, i.e., geologic and climatic change, differ from those caused primarily by man. For example, do present variations in biological populations represent growing, stable, or declining trends related to climatic fluctuations, or do they reflect permanent shifts in species distributions and possible extinction, related to anthropogenic activity. Environmental factors of natural origin influencing growth patterns of populations include short-term seasonal changes in temperature and precipitation, periods of drought or higher than average rainfall extending over decades, catastrophic events recurring on the order of decades, such as hurricanes, or on the order of centuries, for example 100-year floods, and finally long-term climatic trends associated with continental glaciation, spanning millenia. These factors, which can cause major changes in both terrestrial and estuarine habitats (e.g., days below freezing and soil moisture on land, and salinity, light, and nutrients in the estuary), are superimposed on a suite of species that include generation times ranging from several hours in the case of some algal species to decades for many animals, and centuries for some shrubs and trees, and can be expected to affect species with different generation times differently. Environmental factors of anthropogenic origin include increased siltation from erosion with intensification of land use, which can affect light conditions in the estuary, nutrients from fertilizers and sewage which can alter the nutrient composition of the waters, and toxic materials which can selectively affect certain species or life stages of species. In addition, the structure of estuarine habitats is altered by activities such as channelization of wetlands and the building of dams for reservoirs. Changes in the environment resulting from both natural and anthropogenic factors are ultimately translated into changes in species composition and abundance.

In the case of Chesapeake Bay, there is much anecdotal and historical documentation of declines in fish and shellfish populations, particularly those populations used extensively by man. Historical records clearly show local extinctions of submerged aquatic vegetation[15] and changes in waterfowl populations.[10] But there is very little information on populations not of commercial or recreational importance to man, but that nonetheless may have significant interactions with commercially important species. Neither anecdotal nor historical records are complete enough to assess whether the decrease in productivity of particular species represents a normal declining trend or is a precipitous event leading to extinction. Except in rare instances, the historical record of environmental factors, such as precipitation and temperature, is not complete or long enough to display patterns or trends needed to formulate predictive models.

Even if the historical record were complete, it would not contain the prehistoric information necessary for comparing conditions in the estuary prior to the occupation of man with conditions after human occupancy. However, there is preserved in sediments deposited in the Chesapeake Bay and its tributaries a paleontologic record of selected organisms, parts of organisms, and chemicals, which can serve as a surrogate of environmental conditions. At some locations, this record is continuous, covering the history of the estuary since it was formed some 10 to 12 thousand years ago. A disadvantage of the paleontological record is that not all organisms, etc. are preserved equally and some are not preserved at all. Therefore, the sediments do not include a complete suite of all species occupying the area at the time of deposition. Consequently, those organisms that are preserved must be used as indicators, and their present ecological boundaries must be known fairly precisely in order to reconstruct environmental conditions based on their occurrence in the sediments. On the other hand, the paleontological record has a large advantage in that some components, such as pollen and diatoms, representing many terrestrial and estuarine species, are extremely abundant in the sediments, allowing quantitative estimates of populations to be made for different periods of time.

Using the record in the sediments of pollen and seeds of terrestrial and aquatic plants, diatoms, chlorophyll, charcoal, and metals as a surrogate record of environmental conditions, I have compared rates of sediment accumulation and conditions of eutrophication prior to the tenure of European man, when the estuary was controlled by climatic variables, with the most recent 200 to 300 years, during which time the human population in the Chesapeake drainage area has expanded from an estimated few hundred thousand to several million.

In this paper, I shall discuss first the geologic history of the Chesapeake Bay and the history of climatic variation, based on a record of several thousand years. Second, I shall compare sediment accumulation rates in the Chesapeake Bay system before and after the tenure of European man, and address the factors affecting sediment accumulation, based on a record of several hundred years. Third, I shall compare the effect on eutrophication of point source nutrients with non-point source nutrients, using the record in the sediments of a few to several decades. And finally I shall demonstrate the combined effect of sediment and nutrient input on community structure by comparing the kinds of organisms that grew in the Upper Chesapeake Bay before European settlement, 600 to 1000 years ago, with those that occupied the same location after European settlement, 200 years ago and from 50 to 30 years ago.

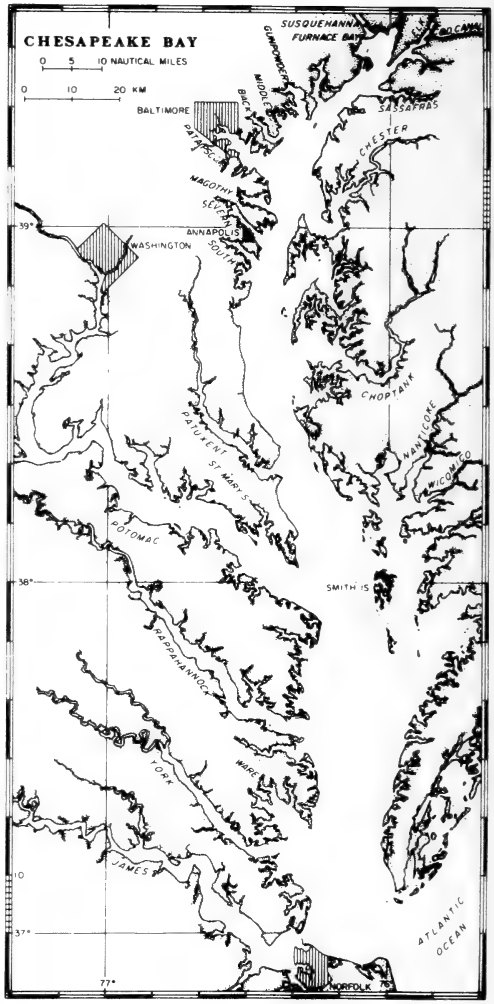

Fig. 1. Map of Chesapeake Bay with tributaries labelled where sediment cores have been collected and analyzed.

Geologic History of the Chesapeake Bay

Frequency of changes in sea level indicated by oxygen isotope curves[4] suggest that the present Chesapeake Bay (Fig. 1) is the latest of several estuaries occupying various parts of the Coastal Plain of Maryland and Virginia over the last several million years. During the warm interglacial periods, each of which lasted for about 10,000 years, existing river valleys were submerged by rising sea level and estuaries formed. Estuarine deposits were subsequently eroded with lowering of sea level during the glacial periods, each of which is estimated to have lasted approximately 100,000 years. Hence, sediments of only the most recent estuary are preserved. However, patchy occurrences of paleochannels filled with estuarine sediments and terraces of different elevations throughout the mid-Atlantic Coastal Plain provide evidence of ancient estuaries[9,11] (J. Halka, unpublished data). The actual location, configuration, and extent of each of the estuaries would have differed depending on sea level elevations, which were not necessarily similar for the different interglacial periods. However, the sequence of events leading to the formation of the estuaries can be assumed to be similar.

Stratigraphic sequences of multiple glacial advances and retreats, contained in some lake deposits, show that the species composition of the flora present in North America over the past two million years resembles the extant North American flora. Species distributions shifted with climatic change, however, from cold at the beginning of the interglacial period to warm at its height and then to cool again with the readvance of the glaciers and the end of the interglacial period. The repeated shift of species distributions in response to glacial advances and retreats in non-estuarine deposits, along with the assumption that changes in sea level corresponding with glacial advance and retreat is the most important variable in the formation and erosion of estuaries, provide strong evidence that the present Chesapeake Bay can be considered an analog of older estuaries in this region. A reconstruction of its climatic history then can be used to project possible future climatic conditions over the next decades and centuries, assuming that geologic history repeats itself. Rapid expansion of the human population within the few hundred years since European settlement distinguishes this estuary from those of the past, however. The record contained in the sediments allows us to compare the imprint of European settlement on the estuary with the effects of climatic change that triggered the accumulation and mass movement of ice, the displacement of sea level by tens of meters, and the migration of plant and animal species thousands of kilometers south of their present ranges.

Schubel[14] presents the following chronology for the evolution of the present Chesapeake Bay. Ten thousand years ago, oceanic waters began to flood the mouth of the old Susquehanna River, now the mouth of Chesapeake Bay. Sea level continued to rise at ~0.2 cm/yr (Fig. 2) so that 8000 years ago, the head of the Chesapeake Bay was at Smith Island; 5000 years ago it had reached Annapolis, and 3000 years ago the head of the Chesapeake Bay was at the mouth of the Sassafras River. About that time, the rise in sea level began to decline to ~0.12 cm/yr, and the Chesapeake Bay reached its present geographic configuration. Recent deposition of estuarine sediments, similar in composition to sediments that filled the paleochannels in the upper two thirds of the present Bay (J. Halka, unpublished data), suggest that infilling of this estuary has begun, and that unless the rate of rise in sea level increases significantly, the Chesapeake Bay has reached its maxium extent.

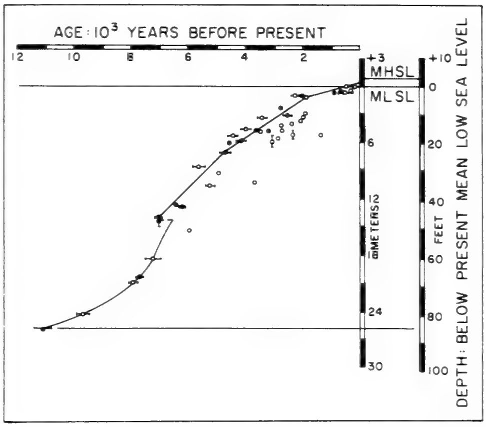

Fig. 2. Sea level curve for the Delaware coastal zone (redrawn from 7). Radiocarbon dated peats from the Patuxent[17] and St. Marys' River (Kraft and Brush, unpublished data) indicate a similar sea level curve for the Chesapeake Bay.

Climatic History of the Chesapeake Bay Area

Pollen contained in radiocarbon-dated sediments deposited at the mouth of the present Chesapeake Bay some 15,000 years ago show that at the end of the last glaciation, the forests in the area consisted mainly of spruce, pine, and fir with some birch and alder.[6] The presence of these boreal species indicates a much colder climate, on the order of 3 to 8°C lower than at present, based on modern isotherms. Ten thousand years ago, oak became abundant as temperatures increased, and rising sea level resulting from melting glaciers began to submerge the ancestral Susquehanna River Valley to form the present Chesapeake Bay. This was followed by increases in hemlock and hickory. Five thousand years ago, the species of plants were similar to those present in the area today, but their abundances fluctuated in response to climatic variations.

Pollen of terrestrial plants extracted from sediment cores collected in the Magothy River (Fig. 1) include a continuous record of many species growing in the forests surrounding the river for the last 4000 years. Vertical (time) profiles of pollen in these cores show major shifts in "dry" and "wet" taxa over that time period (Fig. 3). The period from 2750 B.C. to ~1450 B.C., some 1300 years, was characterized by forests in which black gum (*Nyssa sylvatica*) and sweet gum (*Liquidambar styraciflua*) were the dominant trees. River birch (*Betula nigra*) and ferns belonging to the genus *Osmunda* were also important components of the vegetation. These species are indicators of a wetter environment than characterized the area later. After 1450 B.C., both sweet gum and black gum were greatly reduced. Total pollen production during this early "wet" period was much higher than at any other time prior to European settlement. Since there is a direct relationship between pollen production and the size of tree populations,[5] the increased pollen abundance may signify a greater abundance and size of trees, and high biomass production. After European settlement, when the landscape was largely deforested, increases in pollen abundance are related instead to the longer distances pollen can be transported atmospherically in an unforested terrain, and therefore the larger source area of pollen for eventual

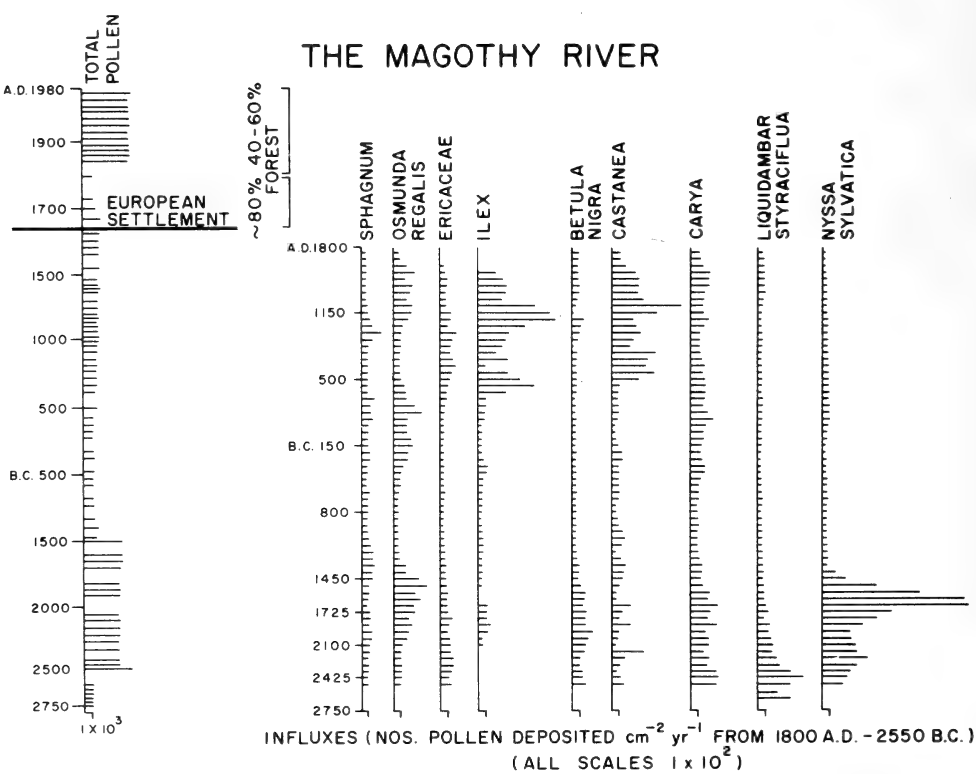

Fig. 3. Influxes of total pollen and pollen of selected taxa plotted against a time scale of 4000 years from a core collected in the Magothy River. Sphagnum moss (*Sphagnum*); royal fern (*Osmunda regalis*); ericaceous shrubs including azalea, blueberry, etc. (Ericaceae); holly (*Ilex*); river birch (*Betula nigra*); chestnut (*Castanea*); hickory (*Carya*); sweet gum (*Liquidambar styraciflua*); black gum (*Nyssa sylvatica*). The influxes are arranged in 65 year intervals, and show major changes in the abundances of plants that occupy dry and wet habitats over the past 4000 years.

deposition.[16] By ~400 A.D., about 1500 years ago, plants that occupy drier sites today, such as holly (*Ilex*), chestnut (*Castanea*), and ericaceous shrubs were the dominant taxa; they remained dominant until European settlement, 300 years ago. Within the time period from ~40 A.D. to ~1700 A.D., however, there were fairly significant oscillations in the abundance of dry taxa. For example, from 400 to 500 and 1000 to 1200, holly and chestnut were much more abundant than in the intervening or subsequent periods.

Pollen, charcoal, and metals extracted from a sediment core taken in the Nanticoke River (Fig. 1), with a 1500 year record, shows a pronounced dry period from 1000 to 1200 A.D., synchronous with one of the dry periods recorded in sediments from the Magothy River. The period is characterized by a high ratio of "dry" taxa (oak, hickory, pine) to "wet" taxa (river birch, sweet gum, black gum), and high charcoal and metal influxes (Fig. 4). The influxes of metals are of a magnitude similar to the historical influxes, believed to be of industrial origin. A more recent sedimentary horizon characterized by an extremely high influx of charcoal in the Magothy River is synchronous with the 1904 fire in Baltimore City. These data lead to the hypothesis that the earlier dry period from 1000 to 1200 A.D. was characterized by intermittent fires, releasing metals from the soil and vegetation, which were then deposited in the estuary.

The pollen record of two herbaceous taxa preserved in sediments deposited in

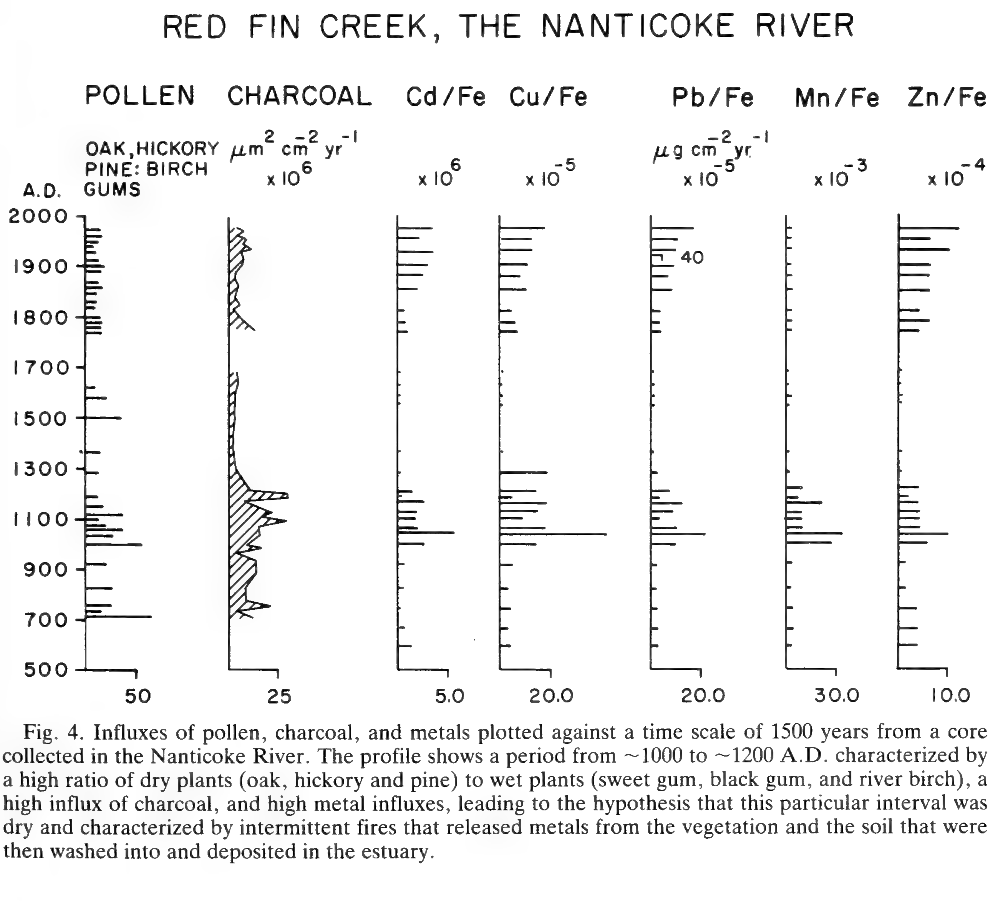

Fig. 4. Influxes of pollen, charcoal, and metals plotted against a time scale of 1500 years from a core collected in the Nanticoke River. The profile shows a period from ~1000 to ~1200 A.D. characterized by a high ratio of dry plants (oak, hickory and pine) to wet plants (sweet gum, black gum, and river birch), a high influx of charcoal, and high metal influxes, leading to the hypothesis that this particular interval was dry and characterized by intermittent fires that released metals from the vegetation and the soil that were then washed into and deposited in the estuary.

the Nanticoke River show variations over the last 200 years that are related in one case to the record of precipitation and in the second to siltation. The precipitation record (Fig. 5) is a reconstruction of rainfall for Philadelphia, Pennsylvania, based on scattered records prior to 1820 and more complete data since that time.[8] Despite deficiencies in the early record, the data show a period of highest precipitation from the mid-1800s to the late 1800s and a dry period from the late 1800s until about 1940. At the same time increasing amounts of land were being cleared for agriculture (Fig. 10). Pollen of burreed (*Sparganium*) preserved in the sediments over the past 200 years indicates that its occurrence is related to precipitation more directly than to land clearance. Burreed grows in open water, in ditches or along the edges of ponds. It began to increase in the late 1700s and early 1800s when there were intermittent years of high precipitation, reaching its maximum at about the time of the longest period of high precipitation. The data suggest that more open water habi-

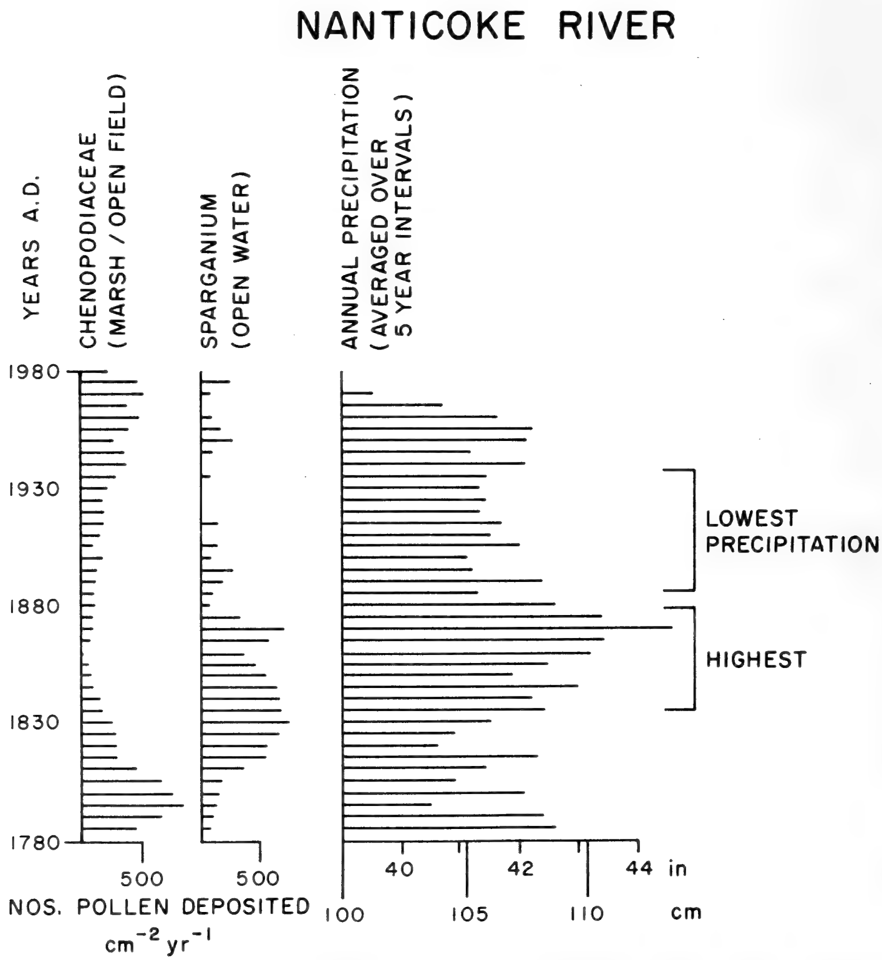

Fig. 5. Influxes of pollen of Chenopodiaceae and burreed (*Sparganium*) plotted against a time scale of 200 years from a core collected in the Nanticoke River. The profile of burreed shows a relationship to the precipitation record, whereas the profile of chenopods is more closely related to the history of land clearance and siltation.

tats became available for the plant as precipitation increased, but with increasing rainfall, the plant, which is an emergent, was drowned out. During the dry period, there were few suitable habitats of open water at the correct depth for its occupancy. Later, its occurrence becomes sporadic with the occurrence of some years of high precipitation intermingled with years of low rainfall.

The occurrence of plants belonging to the Chenopodiaceae, on the other hand, appears to reflect the history of land clearance and the filling in of marshes through siltation. The Chenopodiaceae include plants that grow in marshes and also in fields after initial clearance. The pollen of the different taxa included in this group are not distinguishable. The group as a whole began to increase with initial land clearance, and remained abundant until the marshes were eventually reduced by siltation. With increased crop production, there was less open field space for chenopods. At the same time, increased siltation from intensive agriculture resulted in a reduction of marshlands. These processes are reflected in the decrease in chenopodiaceous pollen from ~1830 to ~1930, a period of intensive agriculture. Later, there is an expansion of this group of plants concurrent with efforts to control soil erosion, reduce siltation, and preserve or enlarge the marshes.

Shifts, over 4000 years, of species occupying dry and wet sites today indicate significant changes in precipitation during that time period. The stratigraphic record also indicates that these changes could occur for relatively short periods, possibly on the order of decades. Such changes would have affected dramatically the flow of fresh water into Chesapeake Bay. This, plus the nature of changes associated with shifts in rainfall, such as high biomass production on the terrain and fires accompanied by high metal influxes into the estuary suggests that the impact on animal species occupying both the land and the water must also have been significant.

Anthropogenic History of the Chesapeake Bay

As stated above, human activities that play a large role in altering estuarine habitats include the introduction of sediment, nutrients, and other chemical substances into estuarine waters, and physical alterations of the estuary and its tributaries. I shall discuss here the effects of sediment and nutrient loading on some estuarine populations.

Sediment accumulation

Using historically dated pollen horizons in the sediment, average rates of sediment accumulation since European settlement were calculated, by dividing the length of the sediment core between the dated horizons by the number of years. An example of a pollen dated core with derived sedimentation rates is shown in Fig. 6. The pollen horizons represent historically documented land clearance for agriculture and the demise of chestnut trees due to disease. Sediment accumulation rates prior to European settlement are calculated between radiocarbon dated horizons, in a manner similar to the calculations based on pollen dated horizons. Average rates of sediment accumulation spanning centuries are highly variable within and between cores (Fig. 7). Despite the variability, however, the rates are always higher after European settlement than before. A summary of the rates of sediment accumulation since European settlement (Table 1) shows that there is a twofold increase in the amount of sediment accumulation when the amount of land cleared changes from ≤20% to 40 to 50%. The increase in sedimentation rates occurs mainly in the upstream and midstream parts of the tributaries. Average sediment accumulation in the downstream areas, close to the mouths of the tributaries, generally is not affected by land clearance.[2]

Using a method for calculating sedimentation rates for any desired increment

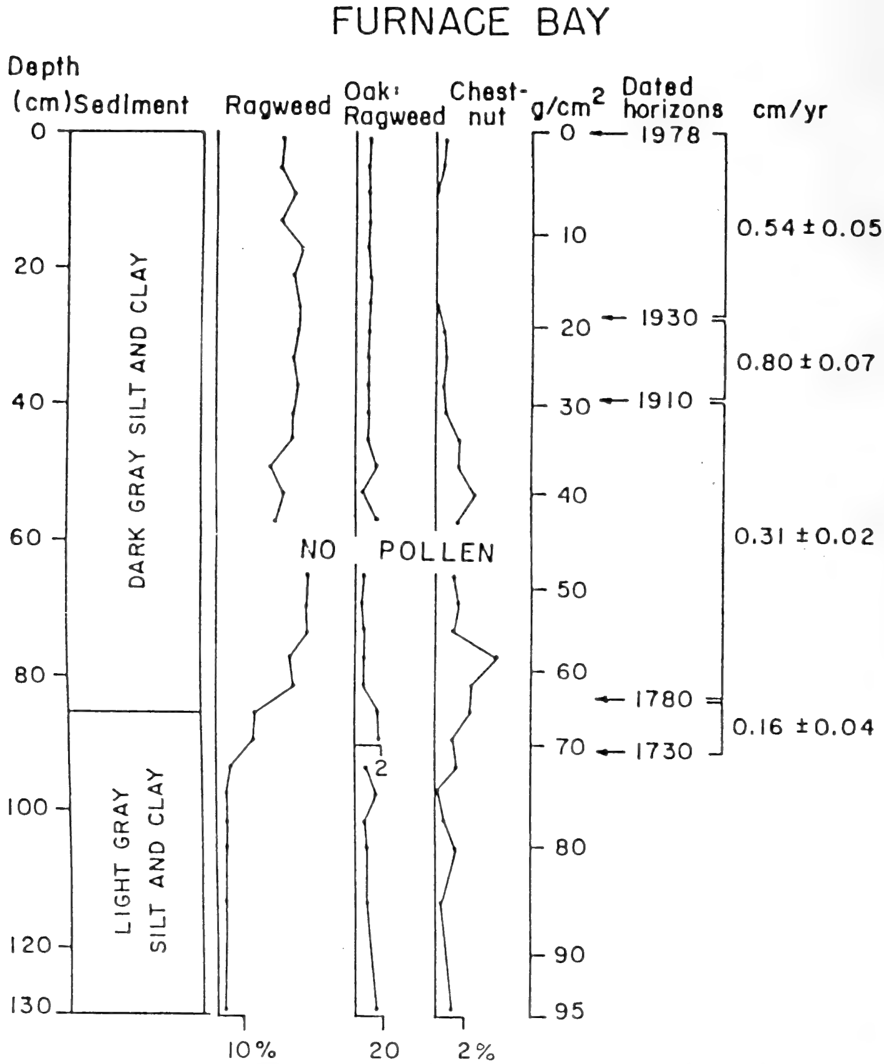

Fig. 6. Pollen chronology of a core collected in Furnace Bay showing four historically dated pollen horizons. 1730: the time of initial agriculture recognized by an increase in ragweed pollen from <1 to 5%. 1780: the time of intensified agriculture recognized by an increase in ragweed pollen to >10%. 1910: the beginning of the chestnut blight recognized by a decrease in chestnut pollen. 1930: the demise of chestnut trees recognized by the absence of chestnut pollen. The occurrence of chestnut pollen at the top of the core represents pollen of Oriental chestnut trees planted in the 1940s. Sedimentation rates are calculated by dividing the length of a core between dated horizons by the number of years.

of a core (Brush, ms in preparation), I compared sedimentation rates in two cores from Furnace Bay (Fig. 1), 0.5 kilometers distant from each other. Principio Creek, a small stream, drains into Furnace Bay. The two cores have generally similar profiles of sediment accumulation (Fig. 8). Prior to European settlement, Core 5, which has the longest record, shows very low rates of sedimentation. After European settlement, rates gradually increase during early and developing agriculture, and are greatest during the period of commercial agriculture. They decrease after

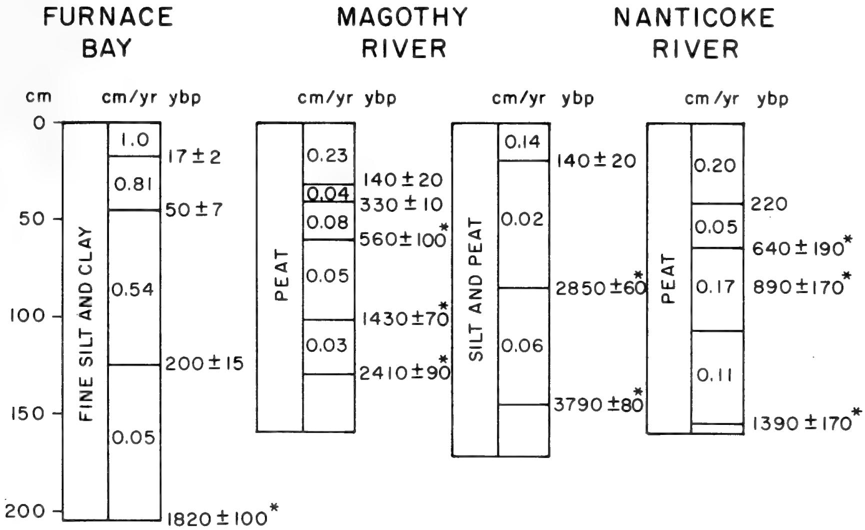

Fig. 7. Average sedimentation rates between pollen and radiocarbon dated horizons in four cores with the longest records collected so far. Asterisked dates are based on radiocarbon measurements; ybp = years before the present. Note the variability in rates within and between cores. Post-European settlement rates are at least four times greater than rates prior to European settlement.

the late 1930s, when soil conservation measures were put into practice; in some areas there was also a decline in agriculture at this time. Two local land activities, however, mask the general pattern, one of which is reflected in each core. Historical maps of the area show that in the late 1700s, the mouth of Principio Creek was close to the location of Core 2. In the eary 1700s, local forest clearance for charcoal production resulted in high sedimentation rates at the mouth of the creek, in proximity to the location of Core 2. Later the channel of Principio Creek migrated, as a delta formed due to increased siltation, and the mouth was relocated eventually close to the location of Core 5. In the 1960s, sand and gravel mining were an important activity in the Furnace Bay area, and resulted in high sedimentation rates at the mouth of the creek, which at this time is reflected in Core 5, but not in Core 2. In addition to an increase in sedimentation rates due to local land clearance, many of the major storms are also reflected by high sedimentation rates in both cores (Fig. 8).

Patterns of sediment accumulation over time, recorded stratigraphically, show that rates of accumulation are controlled by climatic events (storms) and local anthropogenic activity. The lower rates of sediment accumulation at the mouths of the tributaries compared with the upper and middle reaches indicate that fine sediment is not transported far once it enters the estuary (Table 1). The preservation of variations in sedimentation rates attributable to land use and meteorological events over centuries also suggests that there is very little secondary transport of fine sediment after initial deposition, at least in the areas studied.

Eutrophication

A comparison of vertical profiles of sedimentary degradation products (an indicator of algal production and eutrophication) from cores taken in Back River with Middle River (Fig. 1) shows a pronounced difference between the effects of point source and non-point source nutrients.[1] The watersheds of both estuaries

Table 1.—Rates of Sediment Accumulation Since European Settlement*

	<20% land cleared	
	cm/yr	g/cm²/yr
Upstream	0.15 ± 0.03	0.11 ± 0.01
Midstream	0.24 ± 0.05	0.10 ± 0.02
Downstream	0.17 ± 0.01	0.11 ± 0.005
	40–50% land cleared	
Upstream	0.39 ± 0.03	0.20 ± 0.015
Midstream	0.37 ± 0.03	0.20 ± 0.02
Downstream	0.17 ± 0.02	0.15 ± 0.01

*(summarized from Reference 2)

have a similar history of extensive agriculture and urbanization. The Baltimore Sewage Treatment Plant, however, is located on Back River and has been discharging varying amounts of secondarily treated waste water into the river since 1912. Treated sewage discharged into the river doubled between 1917 and 1940. In 1943, a large fraction of the effluent was diverted to the Bethlehem Steel Plant, located on Baltimore Harbor (Fig. 1), to be used for cooling water, accounting for the sharp decline in degradation products of chlorophyll. During a steelworkers' strike, which lasted for four months in 1958, all of the effluent was pumped into Back River, and degradation products of chlorophyll increased. The profile of the influx of sedimentary chlorophyll degradation products, then, mirrors changes in the volume of waste water discharged into the river over time (Fig. 9). The amount of sedimentary chlorophyll resulting from nonpoint source fertilizers prior to 1912 in Back River and throughout the core from Middle River is very small, however, in comparison with the effluent from the sewage treatment plant.

Siltation, Nutrient Input, and Community Structure

For centuries prior to European settlement, Furnace Bay, which drains rich saprolite weathered from igneous rocks, supported abundant and diverse benthic populations, according to the stratigraphic record of seeds of submerged macrophytes and cell walls of diatoms (Fig. 10). The evidence indicates clear water that was rich in nutrients. As the land was cleared, increasing siltation and turbidity reduced the amount of light available to these bottom-dwellers. The occurrence of macrophyte species became sporadic. Reductions in these populations also reduced the habitat for many benthic diatoms that used the submerged grasses as a substrate. Their populations also were reduced. Wherever sewage was introduced into these stressed environments, planktonic diatoms proliferated, reducing still further the light available to benthic populations. Eventually, the benthic species were eliminated. This sequence, which is clearly recorded in the sediments deposited in Furnace Bay,[3] has been demonstrated in experimental ponds,[12] and also has been observed in sediment cores extracted from the Great Lakes.[13]

The sequence of changes following siltation is different in the Ware River (Fig. 1), which drains nutrient-poor Coastal Plain sand. There, prior to European settlement, estuarine populations were extremely sparse, indicating an unproductive, oligotrophic system. The effect of land clearance was to enrich the system with nutrients mainly from fertilizers and to increase its productivity. The composition

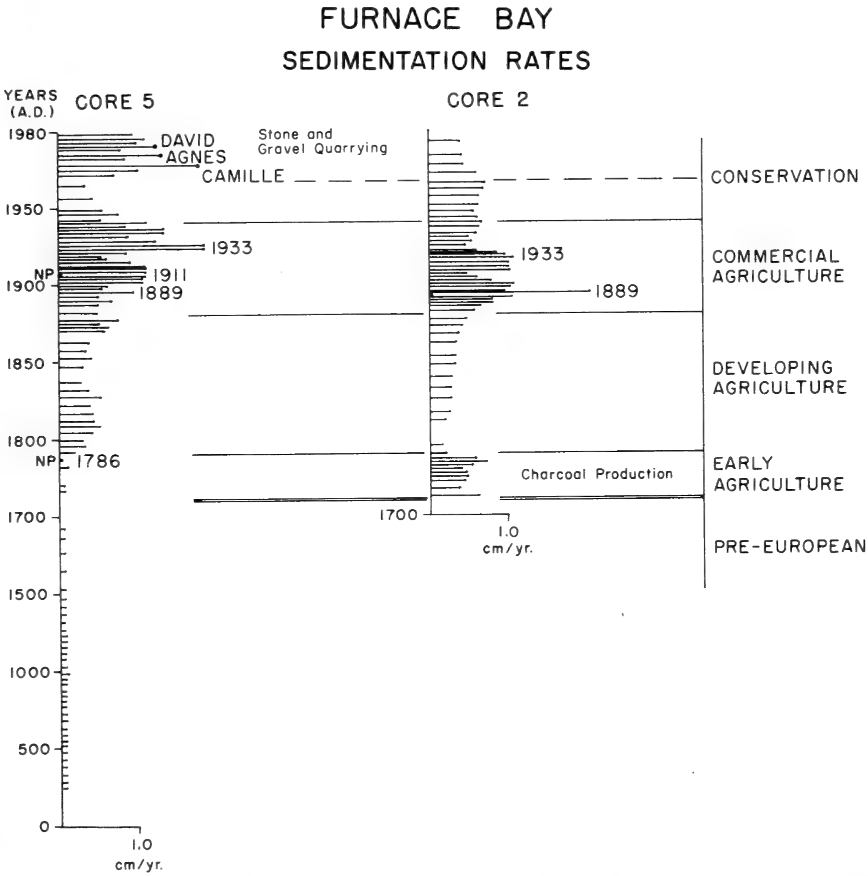

Fig. 8. A comparison of detailed sedimentation rates in two cores collected in Furnace Bay, 0.5 km distant from each other. NP = no pollen in the sediment, indicating an almost instantaneous deposition of a slug of sediment. Zones of no pollen are associated with two major storms in 1786 and 1911. Note the high sedimentation rates associated with major storms of 1889 and 1933 and with Hurricanes Camille, Agnes, and David. The rates of sedimentation show the relationship between land clearance for agriculture and sediment accumulation, as well as the relationship between local forest clearance for charcoal production and stone and gravel quarrying and sediment accumulation. The pattern of sediment accumulation in the cores reflects the migration of the channel with progressive siltation, so that the mouth of the channel which was close to Core 2 in the late 1700s was 0.5 km distant in the vicinity of Core 5 in the late 1900s. This explains why sediment accumulation resulting from charcoal production in the late 1700s is reflected in Core 2 while siltation resulting from quarrying is reflected in Core 5. It also infers that there is very little secondary transport of sediment after initial deposition, at least in this area.

of the diatom flora remains similar throughout, but the abundance increases with increased runoff, except where sewage is introduced. Then, one or two planktonic diatom species become dominant, transforming the system into one similar to Upper Bay tributaries after the introduction of sewage.

Summary

Vertical profiles of seeds and pollen of terrestrial and aquatic plants, degradation products of sedimentary chlorophyll, charcoal, and metals extracted from sediments deposited in Chesapeake Bay tributaries over a period of 4000 years are

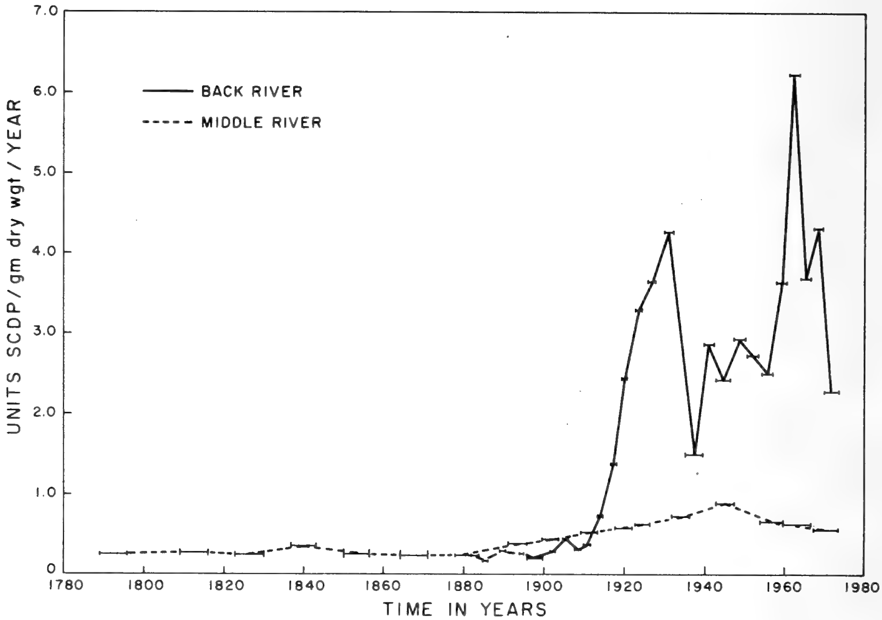

Fig. 9. A comparison of influxes of sedimentary chlorophyll degradation products (SCDP). The source of nutrients was fertilizers (Middle River from the early 1800s to the present and Back River from the early to middle 1800s to 1912) and sewage plus fertilizers (Back River from 1912 to the present). The drop in sedimentary chlorophyll in Back River after 1940 reflects the diversion of part of the sewage into Baltimore Harbor via the Bethlehem Steel Plant, where it was used as cooling water. The increase in sedimentary chlorophyll in the late 1950s reflects the discharge of all of the sewage into Back River during a steelworkers' strike, which lasted for four months in 1958.

characterized by variations, due both to climatic and to anthropogenic factors. The close correspondence between historical records (where they exist) and stratigraphic records provides evidence of the accuracy of the stratigraphic record and its usefulness in the compilation of long-term data bases. For example, comparisons of paired historical and stratigraphic records show: (1) the disappearance of submerged aquatic vegetation within the past decade in the Upper Chesapeake Bay, reflected by the absence of seeds of all species of submerged macrophytes in sediments deposited in that area during the last decade; (2) the demise of chestnut trees between 1920 and 1930, due to disease, reflected by the absence of chestnut pollen in sediments deposited since 1930; (3) fluctuations in the discharge of secondarily treated waste water into an urban estuary since 1912, mirrored by similar fluctuations in the amount of degradation products of chlorophyll found in sediments deposited after 1912; and (4) the 1904 fire in Baltimore, reflected by high concentrations of charcoal in sediments deposited in a neighboring tributary at the time of the fire.

The stratigraphic record shows that, prior to historical records, dramatic shifts in abundances of pollen of dry and wet land plants indicate extreme variations in precipitation extending over decades and centuries during the last few thousand years. The co-occurrence of high metal concentrations, abundant charcoal, and high percentages of pollen of trees that grow in dry habitats, suggest that during dry periods, fires resulted in the discharge of metals, released from burned soil and vegetation, into estuarine waters.

The stratigraphic record also shows that the impact of European man is unique in

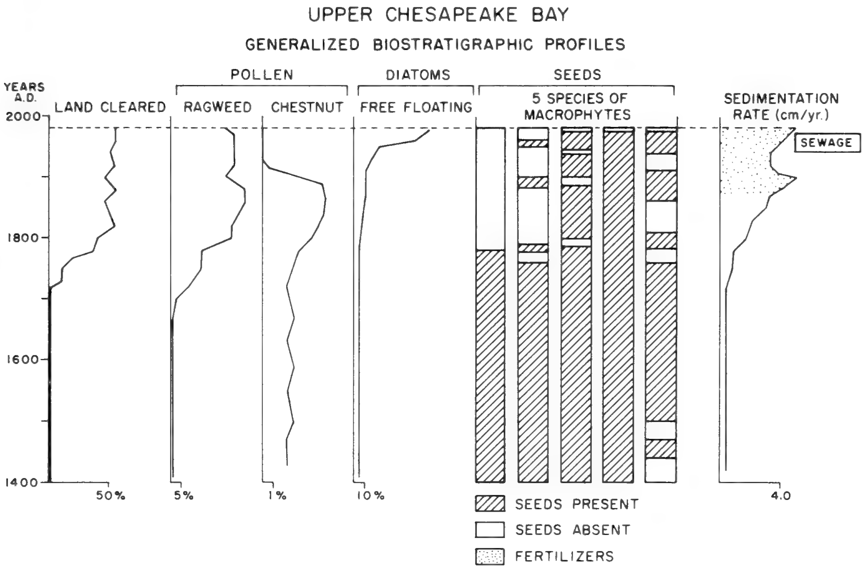

Fig. 10. A generalized biostratigraphic profile compiled from cores collected in Furnace Bay showing changes in populations of submerged macrophytes and diatoms associated with increased sediment and nutrient loading. The system changed from one dominated by diverse and abundant benthic populations to one dominated by planktonic species.

the record of 4000 years. Clearing of land for agriculture and discharging wastes into the estuaries has resulted in sediment, nutrient, and toxic loadings that over time have transformed upper Chesapeake Bay tributaries, draining thick saprolite, from a system that supported diverse and abundant benthic populations to one dominated by planktonic organisms. The change was gradual, with benthic populations disrupted as siltation increased (and light decreased). The record also shows that the effect of increased sediment and nutrient loading is not similar throughout the Bay, but is a complicated response to the hydrologic character of individual tributaries and the geology of the drainage areas. In the Lower Bay, where the majority of tributaries drain nutrient-poor sandy Coastal Plain sediments, low productivity of the estuaries was enhanced with land clearance and use of fertilizers for agriculture, resulting in a greater abundance of species already occupying the areas, and less disruption of populations. Wherever discharged, however, the effect of sewage is an immediate and overwhelming increase in planktonic algae dominated by one or two species.

The stratigraphic record provides a continuous data base, analogous to a long-term monitoring system, which can provide necessary information for the development of practical management objectives—information that is not otherwise available. The record can be exploited beyond the topics of sedimentation and eutrophication discussed in this paper, to address several other environmental questions, including the spatial and temporal dimensions of anoxia, and the effects of deforestation on precipitation and the hydrologic record in general. In order to use the record, it is necessary to determine as precisely as possible the ecological requirements and tolerances of those organisms that will be used as indicators of environmental conditions and to understand as clearly as possible the processes that govern the introduction and distribution of chemicals and other substances in the estuary.

Acknowledgments

I thank J. Halka, F. Scatena, A. Miller, and R. Jacobsen for many discussions and much information during the course of writing this essay. M. Jarosewich compiled much of the historical information. I also am grateful to Dr. Abel Wolman for conversations regarding the use of historical information for making rational decisions. Thanks also to M. G. Wolman and L. M. Brush, and several anonymous reviewers for critical reading of the manuscript and for offering valuable suggestions with regard to the presentation. I am especially grateful to the several state and federal agencies who have funded this research over the years and allowed me to try to find out what I could about the history of the Chesapeake Bay as recorded in the sediments.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 161–172, September 1986

Prehistoric Use of the Chesapeake Estuary: A Diachronic Perspective

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ABSTRACT

During the 12,000 years of prehistoric human occupation of the Chesapeake Bay region, there were pronounced environmental changes that had significant effects upon the Chesapeake Bay and its prehistoric inhabitants. Climatic changes associated with the end of the Pleistocene and post-Pleistocene sea level rise were the most important of these changes. Although the data from the pre-5000 B.P. period are incomplete due to innundation of many coastal sites, intensive utilization of estuarine resources does not seem to have taken place during this early time period. After 5000 B.P., there is a marked increase in the intensity of utilization of coastal resources as the rate of sea level rise slowed. A concommittant series of middle Holocene climatic changes caused a trend toward more sedentary lifeways supported by hunting and gathering of interior and coastal resources. Complex mortuary sites, extensive trade and exchange networks, and developed social ranking characterized many of these nonagricultural societies. Throughout much of the Eastern Shore of the Chesapeake Bay, similar adaptations existed until the time of European Contact. On the Western Shore, agricultural village life developed. Even the agricultural chiefdoms of the Lower Potomac and Virginia Tidewater relied heavily, however, upon the estuarine resources of the Chesapeake Bay for their subsistence needs.

Introduction

This paper provides an overview of prehistoric maritime adaptations for the Chesapeake Bay region. It should be noted that to date there are no data to suggest how the prehistoric inhabitants of the Chesapeake Bay affected its ecology; however, there are abundant data on the ways in which prehistoric peoples adapted their lifeway to the estuarine environment. The configuration, extent, and productivity of the Chesapeake Bay have changed dramatically under the effects of post-Pleistocene sea-level rise during the last 15,000 years[1] and this paper will trace the development of societies adapted to these coastal environments during these changes. Specifically, three basic issues are considered: (1) the chronology of early coastal resource utilization; (2) the development of intensive coastal resource utilization during Mid-Holocene times (3000 B.C.–A.D. 1000) which supported incipient ranked societies; and (3) the relationship between agricultural food production

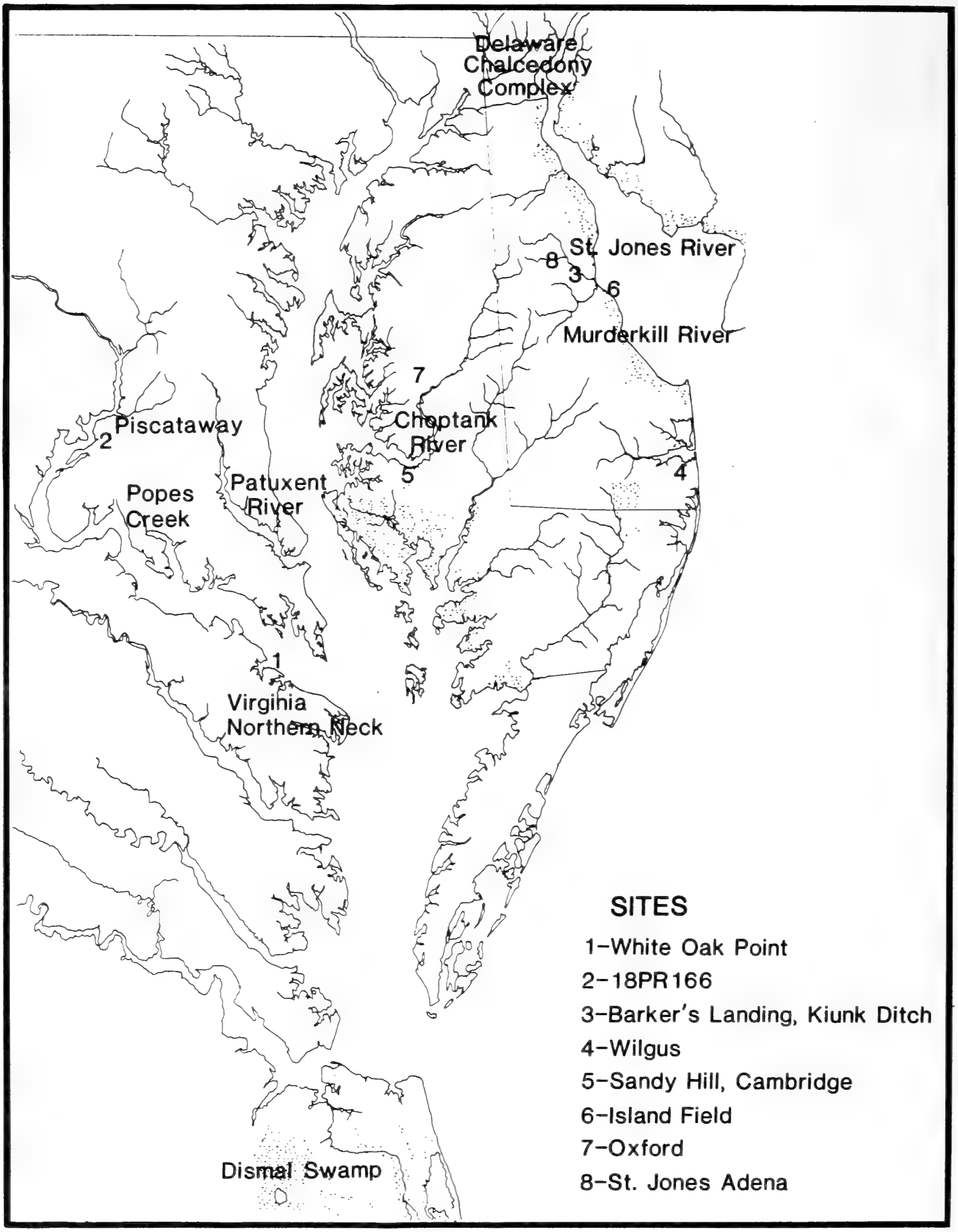

Fig. 1. Site locations.

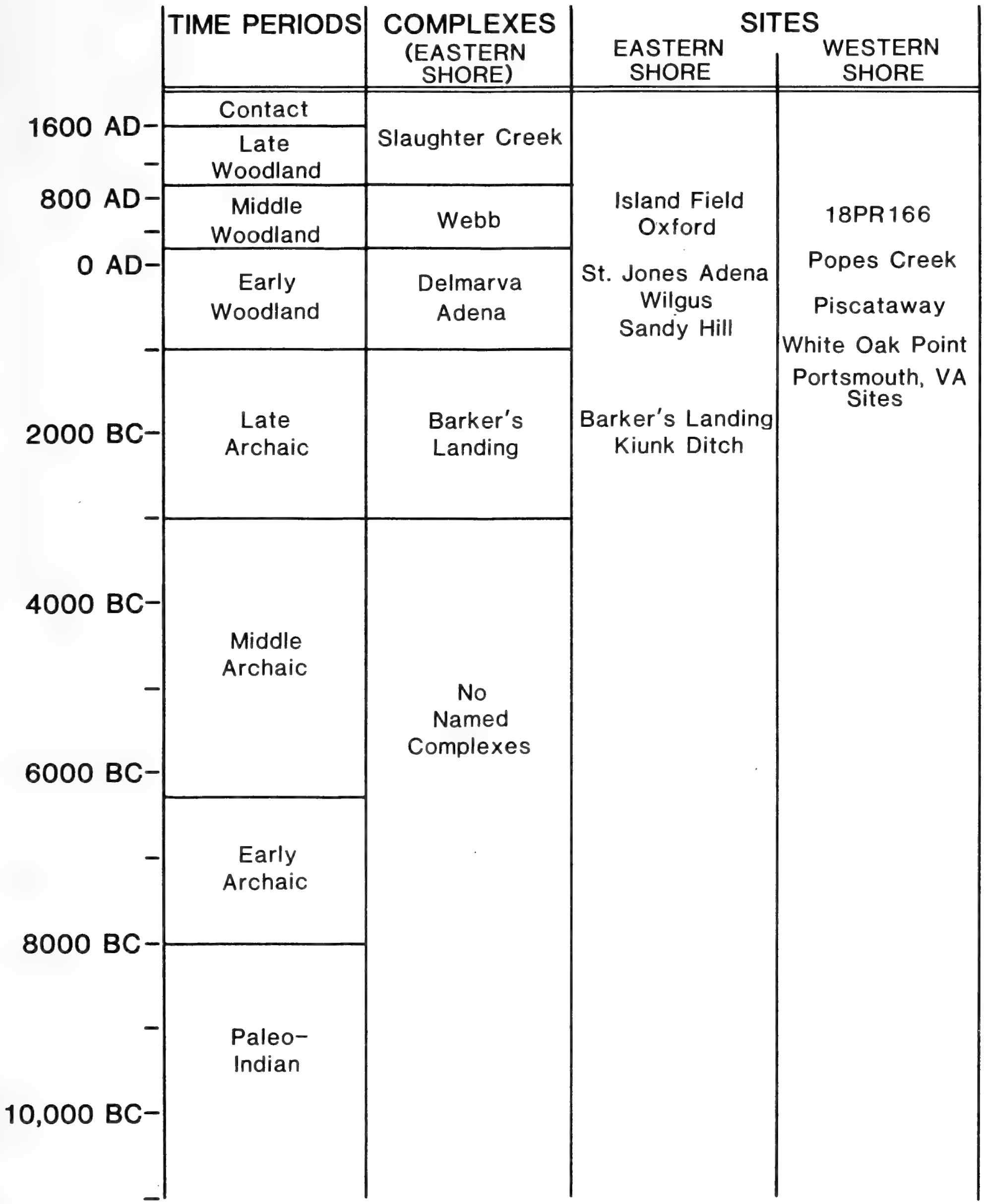

Fig. 2. Time periods, complexes, and sites.

systems and intensive coastal resource utilization in late prehistoric times (A.D. 1000–A.D. 1600).

Many earlier discussions of prehistoric coastal adaptations for Eastern North America suffer from the fact that they do not consider the overall adaptations of the societies utilizing coastal environments.[2] This difficulty will be avoided here by using data from summaries of paleoenvironmental data from the Middle Atlantic area[3–5] along with sea level rise data from the western flank of the Baltimore Canyon geosyncline[6] to develop tentative paleoenvironmental reconstructions for the Chesapeake Bay region. The adaptive strategies of the prehistoric inhabitants of the area as revealed through reconstructions of their settlement-subsistence systems are also considered. Figure 1 shows some of the sites and locations noted in the text and Figure 2 lists the major time periods, complexes, and sites.

Early Holocene Coastal Adaptations

There is some disagreement about the extent, and indeed the possibility, of coastal resource utilization in the Middle Atlantic prior to 3000 B.C. Some researchers[7,8] have reported early Holocene sites with extensive shell midden deposits in the Middle Atlantic region. In both cases the early radiocarbon dates (3000 B.C. and earlier) have been questioned in a critical review of Brennan's work by Snow[2] and in a review of Wilke and Thompson's work by Custer.[9,10]

Furthermore, recently available accelerator radiocarbon dates from one of the middens excavated by Wilke and Thompson show major problems with their shell radiocarbon dates.[11,12]

Extensive shell midden sites pre-dating 3000 B.C. may be buried by sediments in drowned estuaries such as the Chesapeake; however, the configuration and geomorphology of these areas argues against this possibility. Because of their limited tolerance range for temperature and salinity and their immobility,[13,14] shellfish require stable water conditions. Given rapid rates of post-Pleistocene sea level rise in the region prior to 3000 B.C.[6] and the relatively flat slope of most of the Chesapeake estuary, pronounced lateral disruption of temperature and salinity clines occurred prior to 3000 B.C. The absence of extensive shell beds in drill cores from the Delaware Bay prior to 2700 B.C.[1] supports this contention. Unfortunately, comparable and reliable dates and cores are not available for the Chesapeake.

The extent to which estuarine resources may have been utilized by prehistoric societies prior to 3000 B.C. can be ascertained by considering terrestrial settlement-subsistence systems. The traditional view of Eastern North American Paleo-Indian/Early Archaic societies dating from ca. 12,000 B.C. to 6500 B.C. suggests that the hunting of Pleistocene megafauna, such as mastodons, mammoth, and caribou was the dominant resource procurement activity.[15] Recent data and interpretations suggest a hunting adaptation probably focused more on white-tailed deer than on megafauna or tundra-adapted species, such as caribou, for the area south of central Pennsylvania and New Jersey.[16] Collecting of wild plant foods and fishing is also suggested by data from the Shawnee-Minisink Site in the Upper Delaware Valley.[17] A greater emphasis on hunting compared to later time periods, is indicated for the early Holocene, however. Populations during this time period are seen as mobile, although not as mobile as once thought, with movement scheduled on an aseasonal basis around fixed resource sites such as lithic resources or favorable hunting/gathering locales.[18,19] For example, the Delmarva Peninsula data on Paleo-Indian site distributions suggest settlement focused on lithic resources in the area of ancestral Potomac, Nanticoke, and Susquehanna River cobble beds and the Delaware Chalcedony Complex in the northern Delmarva Peninsula.[10,19,20] An additional focal point is the complex of hunting sites in the swampy mid-Delmarva Peninsula drainage divide. In sum, Paleo-Indian group adaptation is seen as emphasizing hunting with the opportunistic use of other gathered resources where available. Locations of fixed and predictable resources provided focal points for population movements.

In light of this adaptation and the nature of coastal resource distributions, some limited use of coastal resources might be expected during the late Pleistocene and early Holocene. Occasional use of shellfish, fish, or sea mammal resources, when available, could have been a part of the collecting strategy of Paleo-Indian groups. Given the adaptations of Paleo-Indians, however, as well as the limited and ephemeral nature of estuarine settings at this time, intensive utilization of estuarine resources would not be expected. An opportunistic, short-term use of these resources, when they were available, is the expected utilization pattern. A possible analogy to this adaptation can be drawn from Fitzhugh's study of types of northern maritime adaptations.[21] Fitzhugh notes a "Modified Interior" adaptation which is characterized as a dual economy with seasonal subsistence on both the coast and the interior. The technology of this adaptation has an interior focus without any specialization for intensive maritime hunting or fishing. Although the Paleo-Indian tool kit is generally characterized as more specialized than the tool kits that Fitzhugh envisions for the Modified Interior adaptation, it is generalized enough to allow the opportunistic exploitation of available sea mammals or estuarine resources.

For the Middle Archaic Period (6500 B.C.–3000 B.C.), Gardner notes that large interior swamps form the main settlement foci with large base camps present throughout the Chesapeake Bay region.[22] Site distribution studies in Delaware[10,23] and Maryland[24–27] support this contention. In most areas, the innundation of pre-3000 B.C. landscapes makes it difficult to generalize further about site distributions. Recent research near Portsmouth, Virginia, at the mouth of the Chesapeake Bay provides additional information, however. Gardner notes that by 8800 B.C. the Chesapeake Bay mouth is innundated, and stable estuarine settings would have been present.[28] Nevertheless, the only sites older than 3000 B.C. in these coastal settings are small procurement sites or transient camps with no associated shell middens. These sites are not as large as sites at the interior swamps and they do not show the same wide range of tools as the large interior sites. In Gardner's view, these coastal sites are outlying components of a regional settlement system that is primarily focused on interior resources. Thus, the main focus of settlement is in areas away from the coast and use of coastal resources is ephemeral, at most, prior to 3000 B.C. Based on present data this generalization holds for most of the Middle Atlantic region.

Middle Holocene Coastal Adaptations

By 3000 B.C., two major environmental changes occurred in the Middle Atlantic and these changes had important effects upon societies living in coastal areas. The first change was a dramatic reduction in the rate of sea level rise.[6] The result of this reduction was an increase in the stability of estuarine settings which allowed the development of more extensive shellfish beds and habitats conducive to spawning of fish, including anadromous species. These contentions are supported by the fact that the earliest extensive shell beds found in the drill cores from the Delaware Bay date to after 3000 B.C.[1] In sum, coastal resources would have been richer, more predictable, and more extensively distributed than ever before. The second change is the onset of dramatic changes in vegetation. Analysis of pollen data[3–5,10,29,30] shows pronounced increases in xeric species such as hickory and pine in Coastal Plain areas, as well as the spread of grasslands. Some data also suggest that periodic oscillations of temperature and moisture availability also characterized this period.[31] Geomorphological evidence and soils analysis suggest that major changes in streamflow patterns and aeolian erosion and deposition occurred at this time as well.[32] Drying of minor and ephemeral streams also seems to have taken place.

The human response to these changes is a shift in settlement patterns and site distributions from Late Archaic through Middle Woodland times (3000 B.C.–A.D. 1000). In general, this shift can be characterized as an emphasis on the rich and predictable resources on the major river valley floodplains and the estuarine marsh settings. In some areas, the adaptations in these settings show stability; in others, however, there are changes through time. Also, the societies in some coastal areas show evidence of increases in social complexity.

In the Outer Coastal Plain at the mouth of the Chesapeake Bay, Gardner has described site distributions for the Dismal Swamp and Portsmouth, Virginia area.[28] Beginning in Late Archaic times (3000 B.C.–1000 B.C.), there is a focus on the Dismal Swamp area and some large base camps are present. By 1000 B.C., however, the beginning of the Early Woodland Period, there is a shift in settlement patterns to coastal areas. These sites are large and are located at junctions of freshwater streams and estuaries. Shellfish utilization is seen as an important subsistence base for these sites although other terrestrial resources played equally important roles. Coastal settlement patterns also include small ephemeral procurement sites and compared to Late Archaic patterns, the Early Woodland Coastal focus seems to be more stable and sedentary. These patterns continue through the Middle Woodland Period and last until A.D. 1000. No indications of trade and exchange or incipient ranked societies are noted by Gardner.

Studies by Potter and Waselkov on Virginia's Northern Neck in the Lower Potomac River Valley represent one of the most complete sets of localized data on coastal adaptations in the Middle Atlantic.[33,34] Potter's study considered settlement patterns on the lower Coan River, a tributary of the Potomac, while Waselkov's studies focused on a single large multicomponent shell midden, the White Oak Point site. Initial use of shellfish, including oyster, periwinkle, soft-shell clam, and ribbed mussel appeared in Late Archaic times and is radiocarbon dated to approximately 2100 B.C.–2000 B.C. A variety of plant foods including hickory nut and grape are also present with a variety of terrestrial fauna including deer, dog, and small mammals. Turtles, snakes, and fish are also present in shell middens. Sites seem to be intermittently occupied small base camps and the major utilization of coastal settings occurred during the early spring. Residence may have been partially sedentary and early studies by Holmes suggest that house structures may have been present at some sites.[35] After 1000 B.C., midden remains show a decrease in a variety of shellfish species utilized, with oysters being utilized most intensively. Because invertebrates provide the major meat source at these coastal sites, a rather specialized subsistence pattern is inferred. These subsistence patterns, established in Early Woodland times, continued until at least A.D. 900. Potter's regional settlement pattern data indicate that after A.D. 200 a series of small and intermediate sized shell middens, complemented by interior upland sites, were present in the Coan River area. These sites are seen as indicative of a seasonal fusion/fission cycle of local and regional bands. Focal adaptations based on molluscs are dominant in the floodplains adjacent to estuaries with supplemental food sources derived from deciduous forest edge settings further inland. By A.D. 900, a series of large midden sites were present in the necklands and are viewed as semi-sedentary villages occupied at least for most of the year. No indications of complex organizations are evident up to A.D. 1000, although some degree of trade and exchange may have been present, as suggested by the presence of chipped stone artifacts manufactured from metarhyolites (which are derived from the Blue Ridge area of western Maryland and central Pennsylvania) in Middle Woodland contexts. The presence of steatite bowls in Late Archaic midden contexts also suggests that long range trade networks may have been in operation as early as 2000 B.C.

Further north on the Potomac River, Gardner has described site distributions in the Popes Creek vicinity as well as along the Piscataway Creek.[28,36] In the Piscataway locality, just south of Washington, a series of large base camps with large hearths and extensive lithic remains are present and are believed to represent camps situated to maximize exploitation of anadromous fish. These sites are initially occupied during Late Archaic times and their utilization continues through the end of Middle Woodland times. Gardner suggests that these sites may have been semi-sedentary and there is evidence of some storage pits with preserved seed remains.[37] Known features at site 18PR166 seem to date primarily from Middle Woodland times and may indicate an intensification of food production. Slightly further south along the Potomac, extensive shell midden sites are noted, including the Popes Creek site. Gardner sees these sites as initially occupied during Early Woodland times (ca. 1000 B.C.) and believes that they may represent semi-sedentary occupations similar to those of the Piscataway area. The intensively utilized resource was shellfish, however, rather than anadromous fish. Similar adaptation patterns continued through Middle Woodland times until approximately A.D. 900, although some fissioning of Middle Woodland communities may have occurred. As was the case in the Coan River studies, the only indications of regional trade and exchange appeared in the form of rhyolite during Middle Woodland times although small quantities of steatite are present in local Late Archaic components. Similar site distributions are present further north, as indicated by survey data from the Patuxent drainage.[24,25]

The middle section of the Delmarva Peninsula provides an interesting contrast to the previously described societies because the Late Archaic-Middle Woodland societies of the middle Delmarva Peninsula show evidences of incipient social ranking including complex cemeteries with mortuary ceremonialism and extensive trade in non-local raw materials and specialized artifact forms. These societies would include the Delmarva Adena groups, as well as some earlier Late Archaic cultures, and later Webb Complex cultures.[9,10,28,38–42] Initially, ca. 3000 B.C., Late Archaic societies of the middle Delmarva Peninsula look very much like other Late Archaic coastal groups of the Middle Atlantic. In Delaware, there are large macro-band base camps sites located at the fresh-water/saltwater interface along the St. Jones and Murderkill Rivers.[9,43] In general, there was an intensified use of major drainage floodplains and an extensified use of interior locales on an ephemeral basis.[44] At the large base camps there are significant accumulations of non-local lithic materials. At the Barker's Landing site in Kent County, Delaware, argillite from the Middle Delaware River Valley (over 150 miles away) is the major lithic resource utilized for the manufacture of narrow bladed stemmed projectile points and broad-spears.[43,45] Debitage indicative of secondary biface production is also present and finds of large primary bifaces, made from large flakes with initial edging, suggest that argillite was traded and exchanged in the form of relatively unprocessed raw materials. Some rhyolite from the Blue Ridge and steatite from the Piedmont are also present at Barker's Landing and other sites in the area. Most of these raw materials were used to produce artifacts that functioned as everyday tools. In a few cases, however, caches of these non-local materials have been noted. One cache from Kiunk Ditch on the lower St. Jones River is significant because it is composed exclusively of 190 early stage bifaces of agillite.[43] These caches are interpreted as the initial conspicuous consumption of non-local raw materials and may be linked to the earliest appearance of artifacts with symbolic functions.[9,10] Preliminary research on the Lower Choptank drainage on the Chesapeake side of the Delmarva Peninsula shows similar artifact and site distributions.[38,39]

By 500 B.C., fully-developed mortuary ceremonialism was present in the Delmarva area, represented by the Delmarva Adena Complex.[40] These sites contain diagnostic Adena biface forms manufactured from lithic materials from Ohio along with copper beads, tubular pipes, gorgets, paint cups, and cut mica. Complex burial treatments mixing in-flesh, secondary, and cremated interments are also present.[46] Recent reconsideration of these sites suggests a hierarchy of site complexity with major mortuary centers differentiated from minor centers.[10,28,39] Also, differential distributions of grave treatments and grave goods within cemeteries suggests the existence of ascribed status categories that cross-cut age and sex lines. A rudimentary "big-man" social organization with ranked kin groups has been hypothesized for these societies. There are no habitation sites directly associated with the larger mortuary sites, although occasionally projectile points and bifaces manufactured from Ohio cherts are present at living sites, such as the Wilgus site in southern Delaware.[47] Living sites of Delmarva Adena groups have been identified in Kent and Sussex County, Delaware, and are found in locations similar to those of Late Archaic sites, except they tend to be slightly further upriver than Late Archaic sites. This change in site locations is seen as a response to movements of the freshwater/saltwater interface brought on by continuing post-Pleistocene sea level rise. In southern Delaware, shellfish middens are linked to Delmarva Adena living sites. Recent data from the Wilgus Site have demonstrated that shellfish utilization is primarily a late winter-early spring activity and that intensive use of *Amaranth* and *Chenopodium* helped to support a semi-sedentary existence.[47] Data from the Wilgus Site also show the occurrence of large amounts of charred amaranth in shell middens that were deposited in late winter and early spring. Because *Amaranth* is available primarily in late summer, storage of seed plant foods is very likely.

Initial research with Delmarva Adena sites on the lower Choptank drainage shows a slightly different pattern for the Chesapeake Bay side of the Delmarva Peninsula. Many large multi-component Late Archaic-Middle Woodland sites are present on the lower reaches of the Choptank River. Delmarva Adena sites are included in this area and contain some of the largest accumulations of burials and specialized Adena artifact forms, such as the Sandy Hill Adena site near Cambridge, Maryland.[42] The composition and overall configurations of sites on the Choptank are similar to the sites on the Delaware side of the Delmarva Peninsula; the primary difference, however, is that the Choptank sites show a greater stability of location through the Woodland period whereas the Delaware groups continue to shift their site locations up the major drainages. This difference is attributed to the varied slope of the drainages. The Choptank gradient is generally steeper than either the St. Jones and the Murderkill and sea level rise would not have had as great an effect on the location of the freshwater/saltwater interface in the Choptank. Consequently, the most productive resource zones would have been more stable on the Chesapeake side of the Delmarva Peninsula.

By A.D. 200, a fissioning of communities is apparent on the Delmarva Peninsula, along with a disappearance of mortuary ceremonialism and extensive trade.[10] By approximately A.D. 700, however, complex mortuary ceremonialism re-emerges in limited areas as evidenced by the Island Field Site and the Oxford Sites.[41,48] There are no single large living sites associated with these sites and a settlement pattern consisting of dispersed small camps characterized most of the Delmarva Peninsula during Middle Woodland times up to A.D. 1000.

A common theme to the middle Holocene coastal adaptations of the Chesapeake region is a focus on especially productive estuarine and riverine environments. Resources utilized vary depending on the particular environmental setting, and include anadromous fish, shellfish, and wild plant foods, especially seeds such as *Amaranth* and *Chenopodium.* Sites in these settings vary between large and small base camps; an overall tendency toward increased sedentism was present, however. Subsistence practices focused on increasingly limited sets of resources as time progressed and community fissioning was prevalent in most areas. Some forms of exchange systems were present in most coastal areas. All of the trends in adaptation noted above can be viewed as adaptations to the effects of the mid-postglacial environmental change. Movement to the highly productive riverine and estuarine settings would have minimized subsistence risks in the face of reduced surface water and climatic oscillations. These zones were sufficiently productive to have allowed the support of high population densities. These higher population densities would have required focal adaptations that in turn required relatively sedentary lifestyles. The processes of sedentism, local population growth, and intensified food production combined to create social environments where some adjustments in social organization became necessary.[49] One possible adjustment would be fissioning of communities into smaller groups as evidenced in many Woodland settlement pattern sequences. This adjustment would be most common in areas where productive zones were large such as the Piscataway area, Popes Creek area, and Northern Neck area. These areas show no evidence of complex organizations and primarily low-level exchange networks.

In areas such as the central Delmarva Peninsula a different pattern seems evident. The productive zones are small along the drainages of the central Delmarva Peninsula and shifts in site distributions up the drainages through time accentuate the focused nature of the adaptation to the freshwater/saltwater interfaces. Additionally, in the Coastal Plain the difference between the rich riverine/estuarine settings and surrounding areas is accentuated by the differential edaphic effects of local soils, especially regarding moisture retention.[50] In these areas, groups would be environmentally circumscribed[51] and fissioning of communities would not be a viable option. Therefore, increases in social complexity and the emergence of incipient ranked societies with big-man organizations redistributing labor occurred as an alternative to community fissioning. Complex mortuary ceremonialism in these areas and the existence of high-level exchange systems are seen as consequences of the development of these more complex social systems.

In sum, the combination of circumscribed environments and intensive coastal resource utilization focusing on a variety of resources created biosocial environments where more complex social organizations had an adaptive advantage. In areas lacking circumscription, sedentary lifeways slowly emerged with little change in basic social organization complexity.

Late Prehistoric Coastal Adaptations

By A.D. 1000, the beginning of the Late Woodland Period, maize agriculture made its appearance in the Middle Atlantic. In some areas there is good evidence that it played an important role in supporting sedentary village life while in other areas there was little impact on societies living in coastal areas. In the Northern Neck area of the western shore of the Chesapeake Bay, Waselkov notes that there is a continued reduction in the varieties of shellfish species utilized, and focused oyster utilization reaches its peak.[34] Also, roasting basins appeared and more varied meat sources were utilized. Waselkov suggests that these trends indicate an intensification of oyster gathering and preparation, perhaps linked to large scale drying of shellfish for storage. Potter's settlement data also indicate a shift to simple maize horticulture at the same time.[33] Between A.D. 900 and 1300 there was an increase in the number of intermediate-sized habitation sites that seem to show a mix of horticulture and shellfish utilization. After A.D. 1300, large villages appeared and the typical site distributions of the Powhatan chiefdom and related petty chiefdoms emerged.[52] Ethnohistorical and archaeological data both indicate that coastal resources are mainly a supplement to the diets of these groups and agricultural food production systems provide the subsistence basis for ranked chiefdoms throughout the western shore of the Chesapeake Bay.

In the Piscataway and Popes Creek area, a marked settlement pattern shift is seen at A.D. 900. Productive coastal environments were abandoned and interior floodplains with large extents of arable land became the locations of sedentary villages.[28] These shifts are associated with the beginning of agriculture in the area and relatively complex societies with ossuaries and possible chiefdom organizations are also present.[53] In the upper Delmarva Peninsula, there is no settlement pattern and subsistence shift moving into Late Woodland times and a hunting and gathering band level organization lasts until European Contact.[10,54]

The middle and lower Delmarva Peninsula presents a variety of subsistence and settlement systems during Late Woodland times; in all parts of the Delmarva Peninsula, however, there is a disruption of the complex social organizations that produced the Delmarva Adena site and the high-level exchange networks.[55] Thomas *et al.* have described several possible site distribution models and subsistence systems for Late Woodland times in Delaware's Coastal Plain.[56] The models propose various levels of sedentism and archaeological examples of three of the models are extant in different areas at the same time.[9,55]

A general pattern that emerges from the Late Woodland data is the fact that where sedentary or semi-sedentary villages appeared, they were supported, at least partially, by some form of agriculture. Also, an initial dispersal into scattered small villages or farmsteads seems to have characterized the initial stages of the adoption of maize agriculture. More simple organizations and less sedentary lifestyles were supported by coastal resources in much the same manner as Middle Woodland societies. Thus, although coastal resources supported some incipient ranked social organizations during Early and Middle Woodland times, the establishment of more complex social organizations and sedentary villages in the Chesapeake Bay region required agriculture.

In conclusion, except for possible small scale effects on local resources, such as shellfish, prehistoric populations had little impact on the ecology of the Chesapeake Bay. Nonetheless, an intricate set of ecological relationships linked prehistoric societies and their surrounding environmental setting. The environmental changes of the middle Holocene, which had significant effects on the Chesapeake estuary, caused some of the most significant cultural changes seen in the 15,000 year time span of prehistoric occupation of the Chesapeake Bay region. Changes in resource distributions triggered an array of interrelated changes in demography, subsistence, and group mobility, which in turn caused major alterations in social structure. The resulting prehistoric societies were nothing like their precursors or their descendants. There can be a lesson for modern societies in the prehistoric archaeological record of the Chesapeake Bay region. Even though we may feel more aloof from the natural environment of the Chesapeake Bay region than our prehistoric predecessors, we are still a part of the same web of ecological relationships. Because we are a part of that web, the human-induced changes in the Chesapeake ecological system of past decades cannot help but have major effects on our future lives. Only the extent and nature of these changes remain to be seen.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 173–187, September 1986

Transforming a "Splendid and Delightsome Land": Colonists and Ecological Change in the Chesapeake 1607–1820

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ABSTRACT

The modern Chesapeake Bay is radically different from the estuary observed by Captain John Smith in 1607. In this paper, historical and archaeological data are used to provide a new perspective on the early Chesapeake and its resources during the colonial period. For the first 150 years of settlement, the use of hoe-based agricultural practices produced little soil erosion. Fish exploitation focused upon benthic species, mostly caught with hooks and lines, and had little impact upon fish populations. About the time of the American Revolution, high population densities and economic factors brought about a change in land use to intensive plow agriculture. This produced major surface erosion and a greatly increased rate of siltation in the tributaries of the Chesapeake. It is hypothesized that this significantly altered the ecology of the tributaries and had an impact upon the reproductive success of a number of fish species. Data from sites on the St. Mary's River in Maryland suggest that the composition of fish species in this tributary was altered by the early 19th century. This paper represents an initial effort to synthesize the archaeological and historical data pertaining to the early Chesapeake and its resources. Through the use of these previously untapped data sources, a unique and detailed perspective on the changing ecology of estuaries can be produced.

The first European colonists in the Chesapeake region encountered a remarkably fertile land covered with virgin forests and interlaced with rivers and streams containing an extraordinary abundance of life. Today, the Chesapeake is a shadow of its former self, with species within its once bountiful waters dramatically reduced in both variety and number. To understand the Chesapeake Bay and its current condition, a perspective that extends beyond the span of a single human life is essential. Processes of change require time for their effects to become readily apparent and the transformation of the Chesapeake is no exception. In this paper, the nature of the estuary during the period of European colonization is explored through the historical and archaeological records. Questions to be addressed include: What species were exploited by the early settlers? How did fish resources and their exploitation change through time? Did colonial land use activities have any impact upon the ecology of the Chesapeake Bay? When did anthropogenic change become a significant factor?

Colonial Demography

The growth and distribution of the colonial population is important and a necessary beginning point. The process of colonizing the Chesapeake region, which began in 1607, was marked by an explosive rate of population growth. By 1635, there were 5000 colonists living in Virginia and this number increased to 60,000 by the end of the century.[1] Maryland experienced an equally rapid growth rate. Following its establishment in 1634 with about 150 settlers, the population grew to 34,000 by 1700, reached the 100,000 mark about 1740 and by the end of the colonial period, there were over 300,000 people in Maryland.[2]

During the 17th century, this population was concentrated in the Tidewater areas. Colonists lived on isolated plantations scattered along the numerous rivers and creeks of the region. Examination of cartographic evidence, especially the Augustine Herman map of 1673, strongly suggests that the colonists had a preference for waterfront property; nearly every plantation depicted by Herman lies immediately adjacent to the water. This distribution is confirmed by archaeological data on site location. Of the 211 known 17th-century sites, 97% lie within one mile of the water and three fourths of these are less than 1000 feet from the shore.[3] This settlement pattern was the result of readily available land, the agricultural focus of the economy, a marketing system reliant upon water transportation and a desire to live near the water for easier travel and exploitation of the estuarine resources.[4]

Only in the 18th century, as the preferred waterfront lands were completely occupied, did settlement expand into the interior sections of the tidewater area and begin in the Piedmont.[5] By the time of the American Revolution, all of the Tidewater and most of the Piedmont of Maryland and Virginia were occupied or actively being settled.

17th-Century Land Use

How did the colonists use the land and what impact did this have upon the estuary? For much of the colonial period, a single staple crop—tobacco—dominated the Chesapeake economy. Tobacco planters attacked the wilderness around them with the axe and hoe, using an agricultural method learned from the Indians. Called slash and burn agriculture, this method first required the cutting of the bark to kill the trees and then the burning of the ground litter to clear the land and release nutrients. Afterward, the rich soil was broken up with hoes, and formed into small hills about one foot high in which tobacco or corn was planted. Good tobacco crops could be obtained from these fields for four or five years, followed by a few years of corn production. The old fields were generally exhausted after six or eight years of use. They were then abandoned to permit reforestation and new fields were cleared. Documents suggest that after about 20 years of lying fallow, the fertility of the old fields was replenished and they could be brought back into production.[6] In essence, planters used a long-term fallow system by which the fields rather than crops were rotated.

With this approach, only a small amount of land was worked each year. One laborer could tend 2 or 3 acres of tobacco, or about 10,000 plants, and another acre or two of corn. In All Hallows Parish, Md., near Annapolis, less than 3% of the land was under cultivation at any one time during the late 17th century.[7] It has been estimated that by the turn of the 18th century in southern Maryland, only about 1.4% of the total land was used to produce the annual tobacco crop.[8] Despite the small quantity of land cultivated annually, a large acreage was needed for the fallow system to operate. To maintain continuous production, 40 to 50 acres of land was required for every laborer.[9]

This agricultural system and the employment of the hoe as the chief agricultural tool have important implications for the Chesapeake during this period. First, only a small portion of land was exposed to surface erosion each year. Second, the agricultural method of planting in hills created a land surface that resisted erosion since the many tiny hills and valleys served to trap much of the water before it could run off. Since the land was recently cleared, the stump-infested nature of the fields also acted to deter the erosional process. This would have been especially effective at retarding erosion on the low relief lands cultivated during the 17th century, but even on lands with greater slope, the hilled fields dotted with stumps would still have provided resistence to soil removal. A third factor is that this agricultural system created a patchwork of land, some being actively farmed, other fields recently abandoned, and former fields in the process of regeneration. Because of this, the cleared fields in production were bordered by vegetated tracts so that runoff water would often have to trickle through scrub or forested tracts before reaching streams, thus helping to trap sediment. An absence of huge open fields also meant that the forces of the wind could not act to erode and deflate the land. As a consequence, soil erosion produced by humans was minimal during the 17th and early 18th centuries and hence, the estuary probably experienced little increase in sediment loads.

Evidence suggests that this form of land use not only produced minimal erosion but preserved the soils' fertility. European travelers to the Chesapeake during the colonial period often commented on the abandoned, exhausted fields and viewed the planters as wasteful and negligent in agricultural matters. What they and many 20th-century agricultural historians failed to realize is that the fields were only temporarily exhausted and the apparent abandonment was merely a replenishment phase during which fertility was restored.[10] This shifting fields system was an efficient, self-sustaining approach that did not destroy soil resources so long as the proper ratio of laborers to land was maintained to allow a sufficient fallow period.[11] Instead of declining crop yields from exhausted soils, recent historical research has revealed that the amount of tobacco produced per laborer in Tidewater Maryland remained essentially constant throughout the colonial period, strong evidence that the soils' fertility was preserved.[12]

17th-Century Fish Usage

What fish resources were exploited during this period and how were they harvested? Historical accounts of the period frequently describe the varieties of fish encountered by the colonists. In 1614, Ralph Hamor wrote that

> For fish, the rivers are plentifully stored with sturgeon, porpoise, bass, rockfish, carp, shad, herring, eel, catfish, perch, flat-fish, trout, sheepshead, drummers, jewfish, crevises, crabs, oysters, and diverse other kinds.[13]

Unfortunately, these accounts cannot be considered solid evidence for the presence of a species since the names were often imprecisely applied, and they reveal little of how abundant different species were. The historical record is nevertheless quite valuable and provides important insights. Household inventories, for example, reveal the types of fishing equipment owned by the colonists at different times. Study of inventories from southern Maryland and York County, Virginia, dating between 1640 and 1745, indicates that the predominant fishing equipment was nothing more elaborate than hooks and lines. In the sample of nearly 900 Maryland households, 95% of the homes with fishing gear only had this; the others had fish gigs or nets in addition to hooks and lines. Surprisingly, most of the homes with fish gear did not own boats or canoes. It thus appears likely that the major fishing method consisted of throwing the baited hook and line out from the shore, with the hook resting on or near the bottom. This is a significant piece of information because it indicates that for most of the colonial period, fishing efforts focused upon the benthic habitat in relatively shallow waters. What fish were being caught by the colonists with this simple technology?

Archaeological Data and Fish Usage

To learn about the nature and exploitation of fish resources in the past, it is necessary to consult the archaeological record which contains the physical remains of the species caught by the colonists. Through the study of these faunal materials, it is possible to reconstruct the meat diet of past peoples and gain insight into the environment they occupied. Archaeological data is especially valuable because it is independent of the historical record, can reveal the species actually exploited by the colonists and provides some insight regarding harvesting intensity.

Archaeological data are not without biases, however. The fish remains found at sites do not represent random samples of all the species in the estuary. Their presence is determined by a variety of factors. Some species, due to flavor or other reasons, may be preferred by a group of people and consistently exploited while other fish are used infrequently or not at all. Nevertheless, when similar species are found at multiple sites in a specific area, it is possible to make some inference regarding species availability in the past. The presence of an animal at a site is also related to the harvesting technology employed by the occupants because a particular type of equipment may be effective in only one habitat or only capture certain species. Fortunately, the study of household inventories and other documents reveals that the hook and line was the primary fishing gear used in the Chesapeake so that the fish remains from most colonial sites were obtained with the same technology and from similar habitats. Another potential bias is the differential preservation of bones. The effects of this problem can be partially accounted for by the analyst through careful selection of the samples and consideration of variables such as soil acidity and site hydrology that affect preservation. Faunal preservation on the sites discussed in this paper ranges from good to excellent.

Despite potential biases, if the archaeological remains from the Chesapeake are studied and interpreted with caution, they can provide a unique temporal perspective on the estuarine ecosystem and its changing resources. Samples of faunal materials are available from 24 households dating between c. 1620 and c. 1750 in Maryland and Virginia.[14] All of these sites are located near the shores of the Chesapeake's tributaries, mostly on the James and Potomac Rivers (Figure 1). Given the simple, agrarian nature of society during the colonial period, there is unlikely to have been much seafood marketing and little evidence exists for commercial fishing until the later 18th century. Most of the sites were tobacco plantations that were self-sufficient in food. Planters raised their own meat and grains and exploited the nearby forests and streams for wild game. Consequently, it is very likely that the species found on these rural sites were obtained locally. Faunal remains from 18th and 19th century urban sites, however, derive from complex marketing networks so that it is difficult or impossible to determine precisely where the fish were obtained. Hence, urban faunal samples offer less potential for evaluating ecological change in estuaries, except on the most general level.

An important variable in the sample of archaeological materials discussed here is

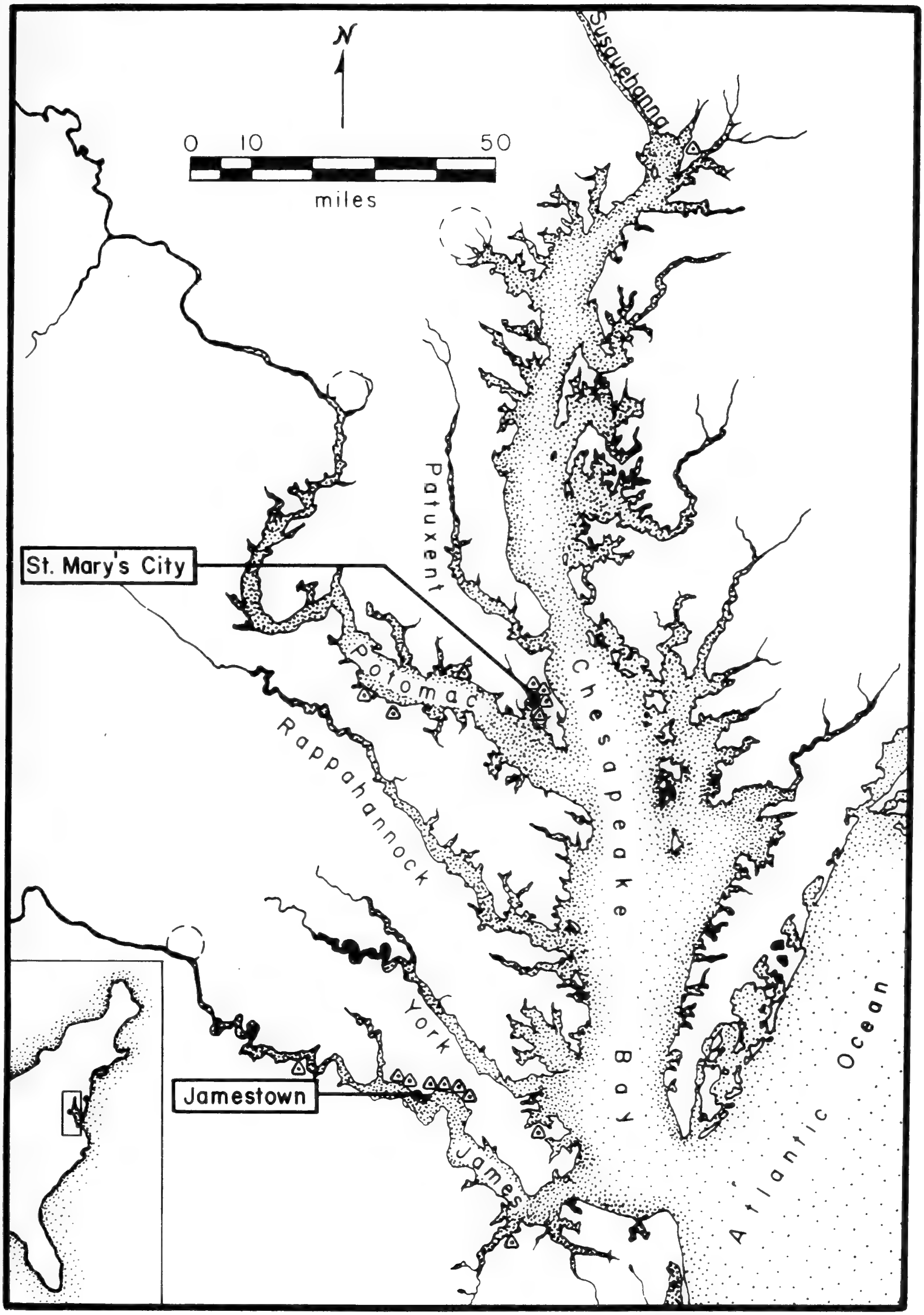

Fig. 1. Distribution of colonial archaeological sites from which faunal samples have been studied.

the geographic location of the sites. This is significant because one of the most powerful environmental factors in estuarine systems is water salinity, which changes from marine to fresh in a discernible gradient. A knowledge of prevailing salinities in the waters adjacent to sites therefore provides the means of dividing the sites into two ecologically meaningful samples. These are (1) sites along low salinity streams near the salt/fresh water interface (Tidal Fresh and Oligohaline), and (2) sites along moderate to high salinity waters (Mesohaline to low Polyhaline).

The low salinity samples are from sites on the James River in the vicinity of Jamestown, which is approximately at the salt/fresh water interface (Figure 1). Fish recovered from these sites are primarily fresh to brackish water species and anadromous fishes (Table 1). Catfish and white perch are the most abundant but bones of the striped bass and longnosed gar are also commonly found. Sturgeon appear consistently on sites located around Jamestown and at Flowerdew Hundred, located further upstream near Hopewell, Virginia.[15] They appear to be more abundant on sites in low salinity areas. Remains of oysters and the blue crab occur on most of the sites, sometimes in large quantities.

Sites located along higher salinity waters yield a quite different assemblage of species. These samples derive primarily from the lower Potomac area, although data are also available from a site on the lower James River and one on the lower Chesapeake near the York River. Marine species predominate on these sites, especially the sheepshead and black drum (Table 1). The sheepshead is the most abundant of all the fish, accounting for a large proportion of the bone and identified individuals. This is consistent with the historical record which suggests that the sheepshead was both abundant and considered an excellent tasting fish. One traveler in 1676 observed that

> A Planter does oftentimes take a dozen or fourteen [Sheepshead] in an hours time with hook and line.[16]

White perch and red drum are consistently recovered from these sites and striped bass bones occur occasionally. Sturgeon remains are rare. Oyster and blue crab, on the other hand, are found in abundance on most sites. It is notable that at the one site on the lower Chesapeake, located adjacent to high salinity waters, sheepshead and red drum predominated with black drum also present in considerable numbers. The remains of blue crab and oyster were also found at this site but no other fish were identified.

Since fishing during this period focused on bottom habitats, it is not surprising that the pelagic feeders such as bluefish, weak-

Table 1—Fish identified in 17th-century archaeological deposits in the Chesapeake region.

	Upper James River	Lower Potomac River
Abundant[1]	Catfish *Ictalurus* sp. White Perch *Morone americana*	Sheepshead *Archosargus probatocephalus*
Common[2]	Striped Bass *Morone saxatilis* Longnosed Gar *Lepisosteus osseus* Sturgeon *Acipenser sturio*	Black Drum *Pogonias cromis* Red Drum *Scianops ocellata* White Perch *Morone americana*
Present[3]	Black Drum *Pogonias cromis* Red Drum *Scianops ocellata* Sheepshead *Archosargus probatocephalus* Sea Trout *Cynoscion* sp. White Sucker *Catostomus commersoni*	Striped Bass *Morone saxatilis* Longnosed Gar *Lepisosteus osseus* Sturgeon *Acipenser sturio* Oyster Toadfish *Opsanus tau*

[1]Species represented by multiple individuals at all sites.
[2]Species represented by one or more individuals at most sites.
[3]Species occasionally represented by a single individual.

fish, and sea trout are absent. It is notable, however, that several species that are present in the modern benthic community were not identified in any archaeological samples. Among these are spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias oundulatus*), and the kingfishes (*Menticirrhus* sp.). Their absence is surprising since they can be taken with the same gear used to catch the species that were present on the sites. This may indicate that the populations of these species were much smaller during the 17th century.

Overall, the species found at sites matches those to be expected on the basis of the prevailing salinities in the adjacent waters. Occasionally, however, marine species such as the black drum and sheepshead occur on sites located in areas where modern water salinities are too low for them. Black drum bones were recovered at a site occupied c. 1660–1680 on the Elk River at the head of the Bay, miles beyond the modern range of this species. Similarly, a few remains of black drum, red drum, and sheepshead have been recovered at 17th-century sites near Jamestown, Virginia, where the waters today are of very low salinity. The presence of these bones could be explained by the marketing of fish caught in higher salinity waters but there is no historical evidence for this and it is unlikely given the settlement pattern and simple economy of the period.

On the other hand, these bones may be evidence that high salinity waters once extended further up the Bay and its tributaries during the summer and early fall, thus extending the range of these marine species. Before the lands in the James and Susquehanna River watersheds were extensively cleared by settlers, it is likely that the rate of fresh water inflow was considerably less than today. This would have permitted saltier waters to move further up the estuary, especially during years of dry weather. Although data from many additional sites are necessary before this can be further evaluated, it does suggest that insights regarding past species and salinity distributions can be derived from the archaeological record.

During the 17th century, seafood was a very important component of the colonists' diet. Archaeological evidence reveals that fish, oysters, and crabs were heavily exploited and they account for up to one fifth of the total meat at some sites; seafood may have been even more significant seasonally.[17] Sheepshead, black drum, sturgeon, striped bass, and catfish were the major contributors to the diet. Nevertheless, given the small number of humans in the Chesapeake during the 17th and early 18th centuries compared to the abundance of resources, is unlikely that the colonists had any impact upon the fish populations.

What about resources that are non-migratory, such as oysters? Shells from most sites of the period are large, suggesting that oysters were abundant and under little harvesting pressure. With the colonists living in plantations thinly scattered along the rivers and creeks, it is unlikely that oysters were overexploited. Was this any different in the vicinity of the few colonial towns?

Data are available from Maryland's 17th century capital of St. Mary's City. Founded in 1634, it was the center of government and chief town in the colony until 1695 when the capital was moved to Annapolis. At its height in the 1680s and 1690s, St. Mary's had perhaps 200 permanent residents, and the population was considerably larger for short periods each year when the courts and Assembly met. Following the move to Annapolis, most of the people left St. Mary's and the former townland was slowly transformed into an agrarian landscape.

Through excavations at several sites in St. Mary's, well dated samples of oyster shells have been obtained from throughout the 17th and early 18th centuries. Analysis of these shells by ecologist Bretton Kent[18] has revealed a significant temporal change in their size (Figure 2). The median size class of shells in the early 17th

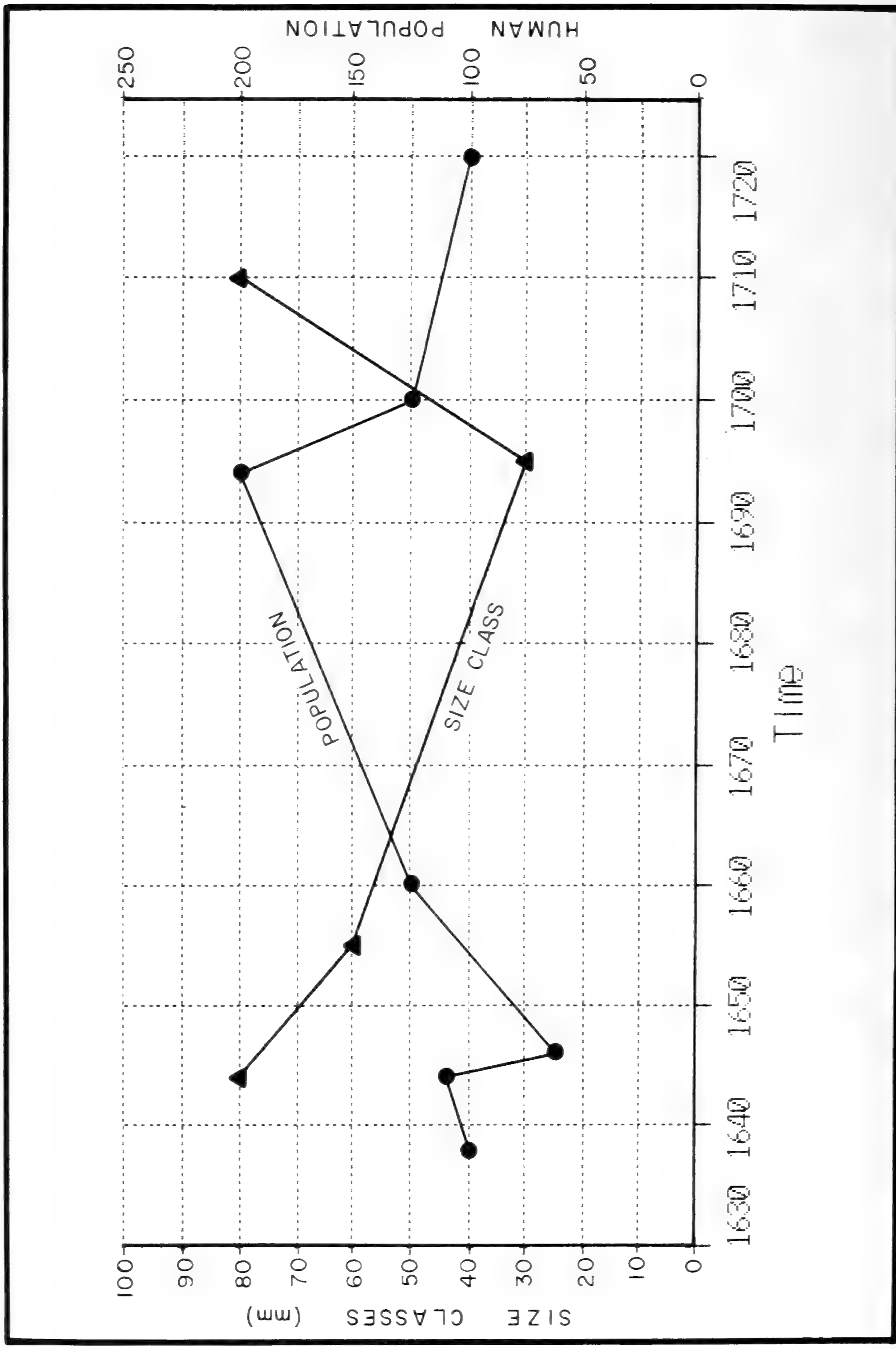

Fig. 2. Relationship of oyster shell size to the human population at St. Mary's City, Maryland.

century was 80 mm, but by the late 17th century, this fell to only 30 mm. In the early 18th century, the size again rises to 80 mm. This rapid change over the course of 60 years is in all probability the result of harvesting pressure on the St. Mary's River oysters. A plot of the estimated human population reveals that there is a strong inverse relationship between shell size and the number of humans. Such a relationship is probably due to the intense exploitation of the oysters so that there was insufficient time for them to reach a large size. When the government moved to Annapolis, the harvesting pressure was quickly reduced. This is the earliest evidence yet found for the overexploitation of a Chesapeake resource and reveals that even small numbers of humans could have a serious impact if harvesting of shellfish was uncontrolled.

18th-Century Fish Usage

Did the 18th-century colonists use the Chesapeake resources in a similar manner and with the same intensity? Archaeological excavations on sites occupied between c. 1700 and c. 1750 indicate a dramatic decline in the frequency of fish remains. On the lower Potomac sites, fish make up only 1.5% of the bone samples, compared to an average of 34% on the 17th-century sites.[19] James River sites display a similar decline. The reasons for this remarkable change are not fully understood, but it is likely that the colonists began to place more emphasis upon domestic animals. Remains of domestic species predominate on the post-1700 sites and they account for over 90% of the estimated available meat. Consequently, wild species no longer served as major staples of the diet in the way they had during the earlier decades of settlement. Thus, the change in the intensity of seafood usage probably relates to a shift in the cultural adaptation of the colonists. Seafood was still consumed but it was more of a supplement than a staple in the diet.

Most of the sites studied from this period are located on the lower Potomac River. The few faunal samples from the James River sites contain the remains of catfish and sturgeon. Sites along the Potomac continue to yield bottom-oriented species such as sheepshead, black drum, red drum, white perch, and oyster toadfish, along with summer flounder (*Paralichthys dentatus*). Examination of household inventories from this period reveal that the hook and line remained the predominant fishing method but suggests a slight increase in the usage of nets. From the John Hicks and Van Sweringen sites in St. Mary's City, Maryland, have come the first identified elements from the bluefish (*Pomatomus saltatrix*) and the herring family (Clupeidae) in the Chesapeake. The later specimens appear to be from menhaden (*Brevoortia tyrannus*), although species identification in this family is difficult with faunal remains. Both are pelagic fish that often feed near the surface, and menhaden are a favorite food of bluefish. Significantly, most members of the herring family cannot be taken with a hook, but must be netted. Examination of the historical situation in St. Mary's and household inventories from the area suggests that these fish were taken with a seine, owned by the most wealthy man in the vicinity. Seine hauling appears to be the only type of net fishing method used with any frequency during the colonial period, and inventories reveal that the seines were generally owned by the very wealthy. Such an ownership pattern is probably due to the fact that the cost of purchasing, maintaining, and using a seine was considerable, and that preparation of the catch required much labor and large amounts of high quality salt for preservation. Lack of good salt was a serious problem throughout the colonial period and it probably deterred the development of commercial fishing.[20] References to the use of seines by wealthy plantation owners, including George Washington, become more common in the second half of the 18th century, and some commercial fishing appears to have begun in the 1760s and 1770s, primarily for herring and shad.[21] Prior to that time, there seems to have been little harvesting of the pelagic fish species in the Chesapeake Bay.

Oyster remains evidence another change in harvesting technology. Shell shape reflects the environment in which an oyster grew and this fact can be used to determine the habitat from which they were harvested. On the 17th century sites, all shells tend to be round or oval in form, indicative of growth on firm bottoms. Certain features of the shells suggest that they were collected from reasonably shallow waters, probably using short rakes or by wading out at low tide. On the 18th century sites, however, a new shell form appears. At the John Hicks site in St. Mary's City (occupied 1721–c. 1740), long narrow shells of large size were recovered. These are the shells of channel oysters, so called because they are found in deeper water habitats with silty bottoms, such as channels. Their form is a product of the oysters' need to rise above the turbidity layer caused by daily tidal action so that their gills are not repeatedly clogged with silt. Their presence at the Hicks site is evidence for the use of a new type of equipment in harvesting—tongs. Historical data from Maryland shows that oyster tongs first appear in household inventories in the early 18th century, and there is evidence that tongs were being used in Virginia by this time.[22] Thus, a new harvesting technology was being employed that permitted oyster beds in deeper waters to be exploited for the first time.

18th-Century Land Use

Evidence regarding human exploitation of the Chesapeake during the colonial period suggests that these activities had minimal impact upon the abundant aquatic resources. What about the resources of the land? Slash and burn agriculture in a long-term fallow system continued throughout much of the 18th century, along with some plowing. During the last decades of the 1700s, however, a complexity of factors—demographic, economic, and social—led to the abandonment of this traditional agricultural system.

The major factor was human demography. By the last quarter of the 18th century, the size of the human population in the Tidewater areas reached the point at which traditional agriculture could no longer continue. Population densities in areas such as All Hallows parish, near Annapolis, Maryland, increased from 18 people per square mile in 1705 to 42 at the beginning of the Revolution. A similar pattern occurred in Prince Georges County, Maryland where the population density reached 39 per square mile by 1776.[23] As such densities were reached, planters essentially ran out of space in which to continue the long-term fallow system. Along with this increased population and reduced availability of lands came a predictable rise in land values. A result was that the system of land tenure changed from one based on long-term leases for up to three lifetimes at low annual rents to short term leases with high rents.[24] This may have been intensified by inflation and the unstable grain and tobacco markets that followed the Revolution, when land owners opted for quick, short-term profits from their holdings. Plantations worked by a tenant family and perhaps a few laborers in a rotating field system often gave way to small leaseholdings intensively cropped by gangs of slaves.

Good markets for grain and the need for greater yields per acre encouraged many planters to turn to grain production and intensive plow agriculture. The shifting field agricultural system, which had yielded good crops for over 150 years, rapidly gave way to a new method of intensive cropping that essentially mined the soil of its fertility while providing little opportunity for it to be renewed through natural processes. Plow agriculture had been used by a growing number of planters since the early 1700s, but it became widespread throughout much of the Tidewater area in the last quarter of the century. A dramatic example of this comes from the tenants inventoried on a tract of land in Charles County, Maryland. In the decades before 1776, only 21% owned plows whereas of those tenants inventoried between 1776 and 1820, 73% owned at least one plow and most possessed several. It has been estimated that the amount of land in agricultural production in southern Maryland rose from about 2% of the total in 1720 to nearly 40% in the early 1800s.[25]

The 18th century also saw the settlement of the Piedmont and clearance of vast tracts of land for agriculture in that area. At the same time, settlement in Pennsylvania resulted in large scale deforestation and the beginnings of agriculture along the Susquehanna River and its tributaries.[26] Most of the agriculture in these areas focused upon grain production using plows. Hoe-based agriculture appears to have given way to the plow much more rapidly in the Piedmont than in the older Tidewater areas.

An understanding of these changes in agriculture is essential because they produced the first major human-induced changes in Chesapeake ecology. In the Piedmont, the large-scale clearance of lands and use of plow agriculture greatly increased rainwater runoff. Hence, the fresh water input into the Chesapeake almost certainly began to increase during the later 18th century. At the same time, soil erosion of the hilly piedmont lands became a serious problem. It was estimated that within 25 years of being cleared, the topsoil on Piedmont fields was washed away,[27] and there are accounts of the large volume of sediment carried by the James river during periods of high water, when it reportedly looked like "a Torrent of Blood."[28] Much of this sediment was probably deposited long before it reached the Chesapeake but it certainly increased turbidity in the streams in the upper Tidewater. This suspension of the chemically rich Piedmont topsoil probably also increased the nutrients in the waters flowing toward the Chesapeake.

In the Tidewater, soil erosion and siltation increased dramatically in a very brief time. Before the Revolution, creeks draining into the Potomac such as Port Tobacco in Charles County and Mattawoman, Piscattaway, and the East Branch creeks in Prince Georges County were all navigable. By 1807, they were silting up and the small ports located along them were being abandoned.[29] Streams on the Eastern Shore of Maryland and near the community of Joppa, north of Baltimore, experienced a similar problem at this time. In Baltimore itself, the port had to be regularly dredged after about 1780.[30] One Tidewater resident, a John Taylor of Carolina County, Virginia, wrote in 1813 that

> . . . few of the channels of the seaboard streams retain any appearance of their natural state, being everywhere obstructed by sands, bogs, bushes and rubbish, so as to form innumerable putrid puddles, pools, and bogs upon the occurrence of every drought.[31]

Most sedimentation in the Chesapeake Bay is a product of natural processes such as shore erosion, which have occurred over thousands of years. Sedimentation produced by the late 18th and 19th century agriculture was different. Consisting largely of fertile topsoil, with a high phosphorous and nitrogen content, this sediment was mostly deposited in the tributaries of the Bay, especially the smaller rivers and creeks. Such a major increase in siltation and the nutrient content of these waters must have had a profound impact upon the ecosystem, especially the benthic habitat. Analysis of sediment samples by Grace Brush confirms that the increased siltation had a serious effect upon the epifauna of these streams (Brush: this volume).

A knowledge of the type of siltation and its location during this period is valuable because it was focused precisely upon the habitat used by many fish species for spawning or as nursery areas for the young. These include forage fish such as killifishes, silversides, and menhaden, and food fish like flounders, herrings, shad, and white perch. The sudden impact of massive quantities of silt and soil chemicals into the tributaries must have had an impact upon the reproductive success of these and other species. The demersal eggs of some fish, for example, would have been more frequently covered by sediment. There is a strong possibility that the reduction in the populations of some species began in the late 18th and early 19th centuries. A brief survey of historical documents failed to uncover any evidence of a change in fish abundance but this is not surprising. Given the extraordinary abundance of fish that originally existed in the Chesapeake, it would have taken a major reduction in their numbers to be noticeable to the casual observer and thus warrant comment. Accurate records of Chesapeake fish harvests only begin in the mid-19th century and the best data are from the 20th century.

This is of relevance because the later 19th century data cannot be considered indicative of the original abundances. Our fisheries records may begin in the midst of a decline rather than before it started. It is also likely that by the mid-19th century, the composition of the Chesapeake fish population was significantly altered from what it had been when colonization began. More research is clearly necessary but the available data imply that changes in the Chesapeake due to anthropogenic factors were well advanced by the time the first accurate fisheries data became available.

What impact did the extensive siltation have on the fish populations in specific tributaries? Is there any real evidence of a change? To answer this, data are necessary from 19th century sites in the same area where earlier sites have also been excavated. Unfortunately, little effort has been directed at sites of this period in the Chesapeake region but there are some data from 19th-century sites in St. Mary's City that warrant consideration.

Like many other streams in Maryland during the late 18th and early 19th centuries, the St. Mary's River experienced a greatly increased rate of siltation. A good example is a small tidal stream, known today as St. John's Pond, which flows into the St. Mary's River at the site of the 17th-century capital. This stream was open to the river in the mid-18th century and sufficiently deep for sailing vessels to enter and tie up at a landing on the interior. Over the course of the next sixty years, this pond filled with a great amount of sediment and the opening to the river began silting shut. An 1824 map reveals that this entrance was so clogged with sediment that a road was constructed across it.

Faunal materials dating to the 19th century are available from the Tolle-Tabbs site, located one quarter mile from St. John's Pond and within a mile of many of the 17th and early 18th-century sites discussed previously. Tolle-Tabbs was a private home, constructed about 1740, and that stood until about 1860. The vast majority of the archaeological deposits on the site date between about 1830 and 1860, when the structure was occupied by a series of tenants. Faunal remains from these deposits have been studied and they display a strikingly different composition from that found on the nearby colonial sites.[32] Elements from striped bass and bluefish are present, along with bones from members of the Family Clupeidae, probably the American shad (*Alosa sapidissima*). The most abundant remains, however, are from the oyster toadfish (*Opsanus tau*) and especially the striped burrfish (*Chilomycterus schoepfi*). No bones of the readily identifiable burrfish have been found on any colonial site in the area, and toadfish remains are rare. Sheepshead and drum bones are completely absent from the Tolle-Tabbs site, in striking contrast to every colonial site in St. Mary's City.

The absence of these species is almost certainly not due to a reluctance to consume them; the sheepshead was widely regarded as one of the best eating fish in the Chesapeake. Both the sheepshead and drum could be easily taken with the simple hook and line, which even a poor tenant family could have afforded. It is inconceivable that they would have ignored such an easily caught and delicious food source if available, while consuming less desirable species such as toadfishes and burrfishes. The most likely explanation is that sheepshead and drums were no longer present in the waters near the site. Toadfish and striped burrfishes may have become more abundant.

Although not yet analyzed, another sample of animal remains from this period has been excavated at the c. 1840 Brome Plantation, also in St. Mary's City. A preliminary examination indicates that sheepshead and drum remains are very rare or absent in this sample. All of this suggests that there was a significant change in the ecology of the St. Mary's estuary between the mid-18th century and the mid-19th century. In particular, the benthic habitat appears to have been significantly modified. Sediment core analysis by Grace Brush (this volume) reveals that the flora and microfauna in the benthic environment of tributaries was severely affected by sedimentation, thus lending support to the archaeological findings. Although the evidence is still quite limited, it suggests that major transformations of the ecology and the fish populations in the St. Mary's River were occurring during the early 19th century. Almost certainly, other tributaries of the Chesapeake were undergoing similar changes.

Archaeology and Ecological Insights: The Potential

Archaeological sites contain a virtually untapped record of past ecosystems. Fish remains from sites attest to the presence of various species and provide some means of inferring relative abundances. Identifying changes in fish distributions and populations is therefore possible. Determining why they changed is a harder task that requires data on many other aspects of the ecosystem, data that are either non-existant or difficult to extract from the historical record. Fortunately, the same pits and cellars that yield fish remains also contain a diversity of ecological data locked in the shell of the oyster.

Oysters can be thought of as small environmental monitors, constantly recording data about the surrounding aquatic environment during their lives. Through the archaeological excavation and dating of the shells, these molluscan sensors can be placed into a precise temporal sequence and their data banks on the Chesapeake environment decoded. Work by Bretton Kent has revealed the diversity of insights obtainable from the shells.[33] Analysis of the various organisms that lived on or in the shell, for example, can reveal the water salinities and nature of the benthic habitat. Many benthic organisms, such as the burrowing sponges *Cliona* sp., have specific salinity requirements and leave indications of their presence on the shells. By identifying and counting their frequencies on shells, an indication of the prevailing salinities in the waters near a site at specific times can be obtained.

Oyster shells can also tell of the bottom conditions in which they grew. Shell shape, for example, reflects the nature of the substratum upon which an oyster lived. By studying this and other attributes of the shell, the changing bottom conditions in specific locations can be traced over hundreds and perhaps thousands of years. There is the possibility that many collections of oysters from sites can also provide precisely dated samples of bottom sediments. This is due to the activities of the oyster mud worm (*Polydora websteri*) which burrows into the edges of the shell and creates cavities that later fill with sediment. On many shells from colonial sites, these "mud blisters" remain intact and when opened, are found to contain sediment. With sufficient shell collections from a given locality, it is possible that a sequence of well dated sediment samples can be obtained.

Other ecological clues lie hidden in the hinge area of the oyster shell. This is a location where annual, seasonal, and probably daily growth rings are laid down and they can be read through various analytic methods. Variation of average growth rates in shells from different periods could be used to learn how nutrient availability changed in a tributary. Climatic information can also be obtained from these shells since major storms, periods of severe cold weather or drought all influence shell growth by affecting the surrounding aquatic environment. The collection and study of oyster shell samples from rural sites along the Chesapeake offers tremendous potential for tracing the past ecology of the estuary. When combined with data from archaeological fish remains, these independent sources of evidence can provide a remarkable record of the estuarine conditions and help determine how and why they have changed.

Summary and Conclusions

Review of the historical and archaeological records from the 17th and 18th-century Chesapeake provides a number of important insights pertaining to the colonists' use and transformation of this estuary. Over most of the colonial period, the colonists appear to have had little impact upon the Bay's ecosystem. Agricultural practices were of the type that required large quantities of land and provided sustained yields without permanently degrading soil resources or causing serious erosion. Fishing activities focused on the benthic habitat over most of the colonial period. Given the simple fishing equipment and small human populations, it is unlikely that harvesting pressure was sufficient to have any impact upon the fish populations.

Only in the late colonial period did significant ecological change begin to occur. Large sections of the Piedmont were under cultivation or being actively cleared for plow agriculture. In the Tidewater area, due to both human demography and economic forces, the land tenure system and agricultural practices changed during the last quarter of the 18th century. Evidence suggests that after 150 years of use, the soil conserving method of shifting field agriculture was rather quickly abandoned for an "Improved" agriculture based on intensive plowing and field fertilization. The new method may have provided better yields but its unanticipated side effects were widespread surface erosion, deterioration of soil resources, and rapid sedimentation in the tributaries of the Chesapeake. By 1820, significant changes were occurring in estuarine ecology and the aquatic resources. This is a clear example of the impact that changing land use practices can have on estuaries.

The Chesapeake region has been occupied for thousands of years by a variety of cultures who perceived and exploited the environment in a diversity of ways. These peoples have left us a remarkable legacy, formed quite unintentionally through the process of daily life. By depositing artifacts and food waste into the ground, they created thousands of time capsules that not only tell of their lives but of the environment they inhabited. Through the study of this archaeological record, and the surviving historical accounts, it is possible to gain a unique insight into the evolution of the Chesapeake. This paper represents a first effort at synthesizing the research findings of archaeologists and historians to better understand how and why the Chesapeake has changed. These data sources have tremendous potential for the development of the temporal perspective necessary to preserve and nurture this magnificent estuary.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 188–198, September 1986

Chesapeake Fisheries and Resource Stress in the 19th Century

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ABSTRACT

Chesapeake Bay contained large populations of fish, crabs, shellfish, and aquatic plants at the beginning of the 19th century, although harvests were small. Vast spring runs of anadromous fish were increasingly exploited to provide millions of pounds annually until closing of rivers by dams, heavy predation by fishing, and perhaps pollution took their toll. For oysters, the coincidence of the importation of deep-water dredges, development of new technologies, high demand, and the discovery of large unknown beds resulted in a new important industry and changed the ecology of the Bay. The effects of poor management were also discovered. Abundant blue crabs were caught and processed as new methods were perfected and transportation became available. Waterfowl were harvested for food and for sport in large numbers. The environment, which had been injured by sediments from land, received growing quantities of human and industrial wastes, and the first steps toward water pollution prevention were initiated.

The century provides dramatic and large-scale examples of discovery, innovations, exploitation, and decline in fisheries and of the dawning recognition of the needs for scientific understanding, wise management, and the control of pollution.

The Beginning of the Century

As the century opened, the living resources present in the tidal Chesapeake Bay system were rich in variety and enormous in quantity. Vast spring migratory runs of shad, herring, and sturgeon entered the Bay and moved to the tributaries to spawn. Unmeasured but certainly massive populations of oysters, crabs, menhaden and sea-sourced fish were present. Clouds of waterfowl had been observed since colonial days and their presence gives evidence of abundant stands of aquatic vegetation. The high diversity of fish, game, and birds was noted in many reports. As always, the stocks were certainly variable, as noted in the accounts of George Washington and others.

The harvest at that time cannot be measured because there was no system or habit of permanent recording. The scattered records and occasional relevant writings show, however, that the harvest was modest, local, and highly seasonal. Only a few fishing methods were available, those imported by the immigrants or adapted from native Indian practices. These included simple short tongs for shallow-water oysters, small seines, wiers, and primitive fish hooks. The largest harvest was from the spring runs of fish. According to writings of the period, crabs and oysters were not highly esteemed, although oysters were significant in the local tidewater diet (Wharton 1957, Middleton 1953). Colonial management by England had never favored fisheries in the Maryland and Virginia colonies, which were expected to produce tobacco while fishing was encouraged in New England. "Good" salt from Lisbon, Italy, and Cabo Verde was prohibited for the Chesapeake colonies, and only "weak" and inadequate salt from Liverpool was permitted (Beitzell 1968, Bayliff 1971). One of the results of liberation was improvement in the preservation of fish. By 1800, significant production was only beginning.

From the perspective of modern knowledge about the Chesapeake Bay system, we can speculate with a degree of confidence about the environment in the Bay around 1800. All of the many habitats now present were in the system (except for the polluted ones). There was a wide variety of depths and sediment types, the broad seasonal swings in temperature and rainfall were similar to the present, the full gradients from fresh water to marine salinity existed with considerable variation, and the physical circulation patterns were not greatly different. Most of the same species lived in or around the Bay, although significant changes have occurred from introductions and reductions or perhaps extirpations. The populations of humans were relatively small, and included about 350,000 in Maryland and 865,000 in Virginia. Clusters of people were so small that "city" is hardly an appropriate word. Wastes were dumped freely into the nearest waterway, where local effects probably occurred.

The human population had, however, achieved one change that had a substantial effect on the estuary. Land had been rapidly and extensively cleared of trees in the tidewater region, principally for the bare-field culture of tobacco. Iron furnaces were common, demanding mining of about three tons of ore per day and 300 bushels of charcoal to reduce it, causing additional land clearing. These and other activities resulted in massive surface erosion, faster run-off of water, turbidity, filling of head-water areas, larger chemical burdens to the Bay, and eventual down-stream shifts in the salinity patterns.

Still, the observed vast populations of waterfowl and fish provide evidence that they had not yet been destroyed by sediment, increased turbidity, or toxicants.

A Century of Harvesting the Migratory Fish

Shad and several species of herring undertook an anadromous migration from the ocean to spawning grounds during about six weeks of each spring. Gear were developed or adapted to harvest them while they were crowded in the headwater and tributary areas. Runs extended up the Susquehanna into New York State, and at least 40 fishing sites were regularly used along the upper River from Northumberland to Towanda (McDonald 1887). In other tributaries, the runs extended to the fall line. In the upper Bay and Susquehanna River, large floats of logs were constructed and equipped with landing ramps and processing houses (Wright 1967). These were the foci for the operation of 10–15 long seines, which sometimes caught 600 barrels per haul, with 100 or more men employed for each float. Fish were cut, salted, placed in hogsheads and transported by wagons. Shad are described as weighing 3–9 pounds, and as much as 13 (McDonald 1887).

The short-term employees on the floats hardly present a romantic image of good old days. They have been described as wretched, scarcely clothed, and mostly drunk—bringing up the rear of the human race (Royall 1826). Farther up the Susquehanna, near the Maryland-Pennsylvania line, one haul in 1827 is reported to have yielded 100 wagon loads of fish, estimated to include 15,000,000 shad. A 1835 gazeteer published in Virginia stated that 22,500,000 shad and 750,000,000 herring were caught per year in the Potomac River (Bayliff 1971).

Changes were beginning. The first dams in the Susquehanna, far upstream, were built about 1830, and canals were built that diverted a small portion of the river flow. Perhaps the importation and development of new fishing gear, permitting unprecedented harvests from deeper and more open waters, was more important (McDonald 1887). In 1835, gill nets were the principal gear for fish. Pound nets, blocking areas from shallow to moderately deep water, were imported about 1858 from New Jersey, and the revolutionary open-water purse net was brought in from Long Island in 1865. The fisheries were, however, still principally focused on the spring and fall runs, although many new species were taken by these additional techniques.

From 1875 until the end of the century, there was a phenomenal interest in the use of hatcheries to augment stocks. Up to 10,000,000 shad fry were hatched and released each year and efforts were made to hatch salmon, lake trout, European carp, rock and even tench! (Ferguson and Hughlett 1880). Mobile hatchery vessels were created to move among the spawning grounds to permit prompt hatching and release, while other hatcheries were operated at various sites on land. Even the excellent zoologist W. K. Brooks was caught up in the enthusiasm, and described shad as "a domesticated animal," for which "intelligence and knowledge of nature . . . have enabled man to keep up the supply by artificial means" (Brooks 1893, p. 239). It is useful to introduce a later comment, based on extensive review of shad fisheries and management in the Chesapeake and elsewhere (Mansueti and Kolb 1953, p. 85):

> ". . . the honest but mistaken feeling toward hatcheries which seized not only fishermen but biologists at the turn of the century, although even then the premise should not have stood up under more objective scrutiny."

By 1880, there were 160 pound nets in Virginia and two in Maryland, and 60 menhaden factories employed about 800 men (Goode *et al.* 1887). Shad, bluefish, sea trout, menhaden, and mackerel were important to the fisheries. Up to 14,000,000 pounds of shad were taken in the Susquehanna, where fisheries had been reduced down-stream to the Columbia dam, about 40 miles above tidal waters. Gill nets were still the most important gear, and hundreds were fished each night in season in the upper Bay and other tributary areas. Twenty large seines, up to a mile in length, were in use along with the attendant floats or batteries near the mouth of the Susquehanna. Some nets required 2½ days for emptying. The menhaden "swarming our waters in countless myriads" were harvested for oil, fertilizer, and bait (Goode *et al.* 1887). The rock or striped bass was caught only in small quantities.

In the 1880s and 1890s, there was an explosion of printed material of several types on the fisheries of Chesapeake Bay and other areas in the United States. They included a major seven-volume survey and description of the "Fisheries and Fisheries Industries of the United States" by Goode and many others for the U.S. Commission of Fish and Fisheries, scientific summaries (Brooks 1891, 1905; Bean 1883; Ryder 1890; etc.), popular summaries (Brooks 1893; Brooks and Knower 1893), federal and state agency reports (Carroll 1880; Ferguson and Hughlett 1880; etc.), and illustrated newspaper accounts (Anon. 1873, 1874, 1882, 1883a and 1883b). It is not possible to summarize these here, but they describe vigorous and imaginative fisheries, rapidly expanding the exploitation of the Bay's bounty. Figures 1–5 present the available estimates of landings for important finfish. In the 19th century, shad catch increased dramatically (Fig. 1). The take of rock or striped bass (Fig. 2) and of croaker (Fig. 3) was small. Bluefish were

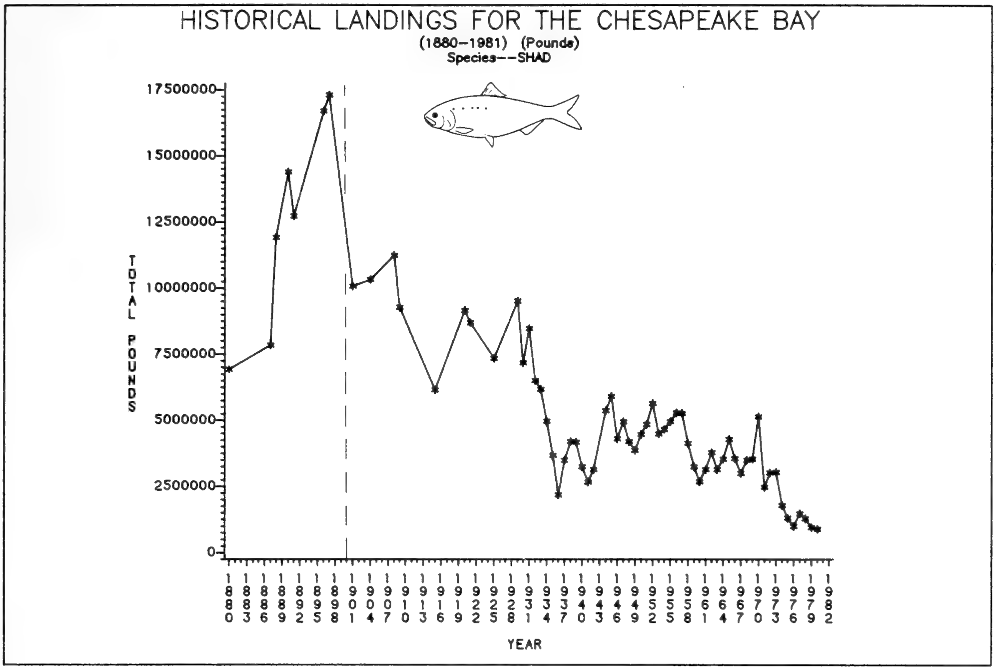

Fig. 1. Available data on landings of shad, *Alosa sapidissima,* for Chesapeake Bay, 1880–1981.

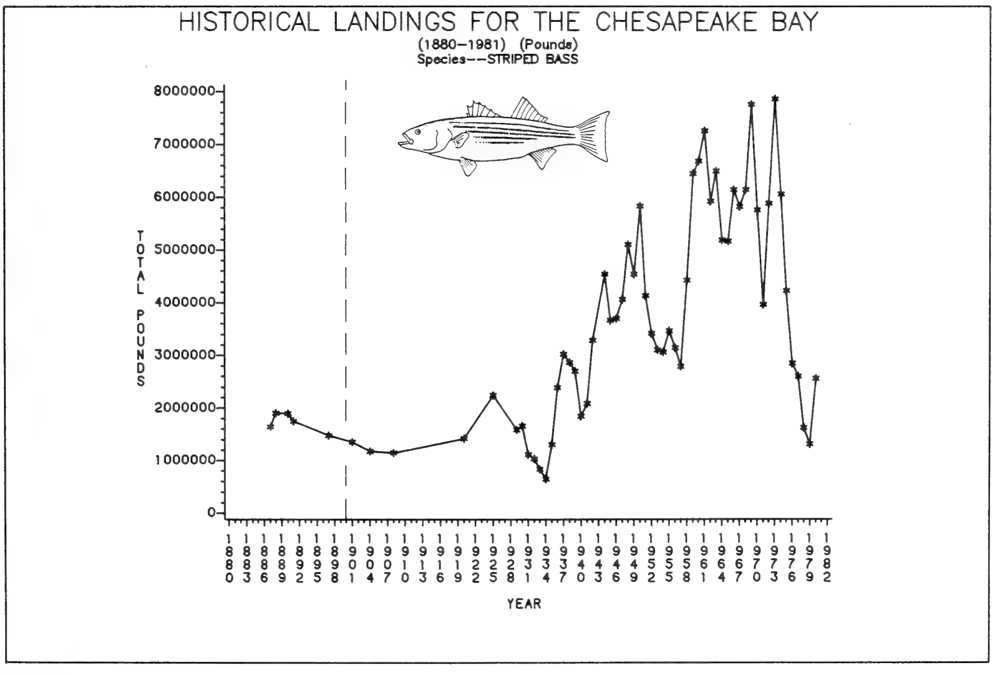

Fig. 2. Available data on landings of rock or striped bass, *Morone striatus,* for Chesapeake Bay, 1880–1981.

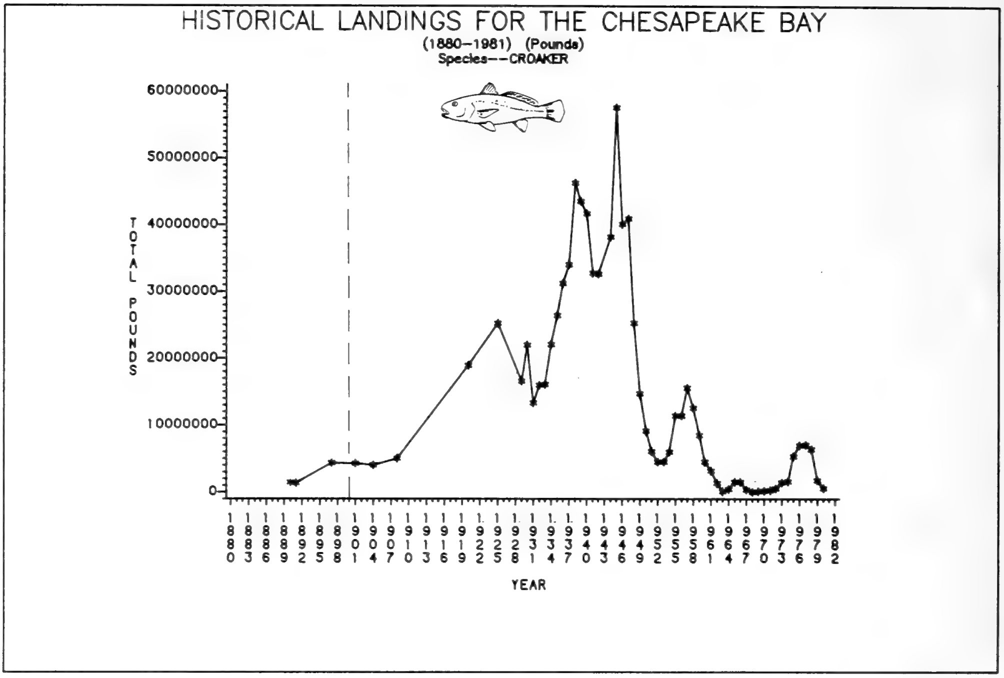

Fig. 3. Available data on landings of croaker, *Micropogon undulatus,* for Chesapeake Bay, 1880–1981.

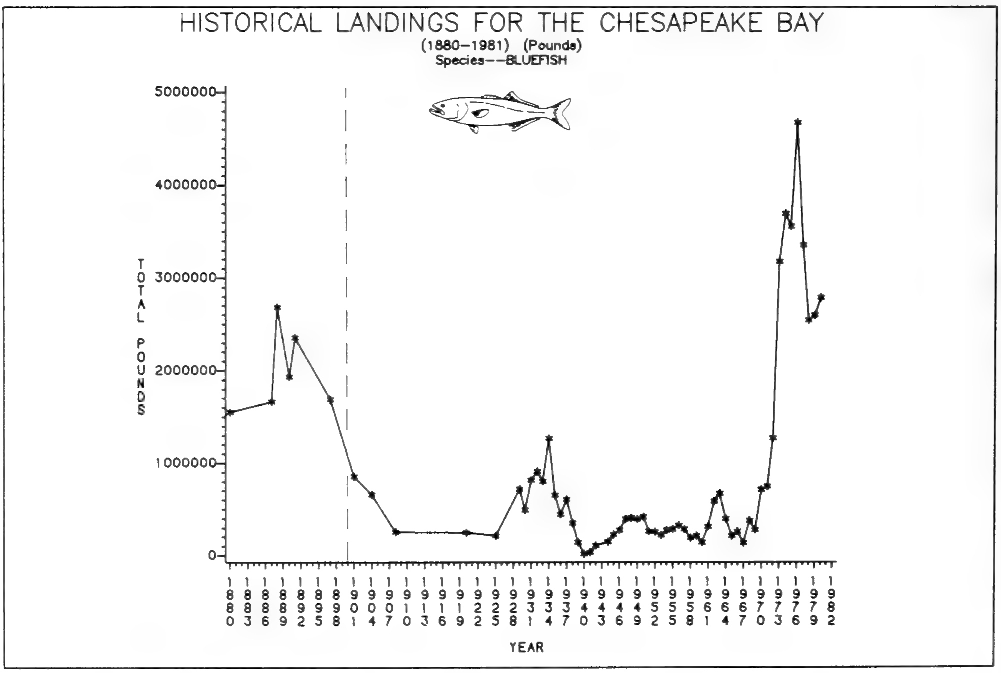

Fig. 4. Available data on landings of bluefish, *Pomotomus saltatrix,* for Chesapeake Bay, 1880–1981.

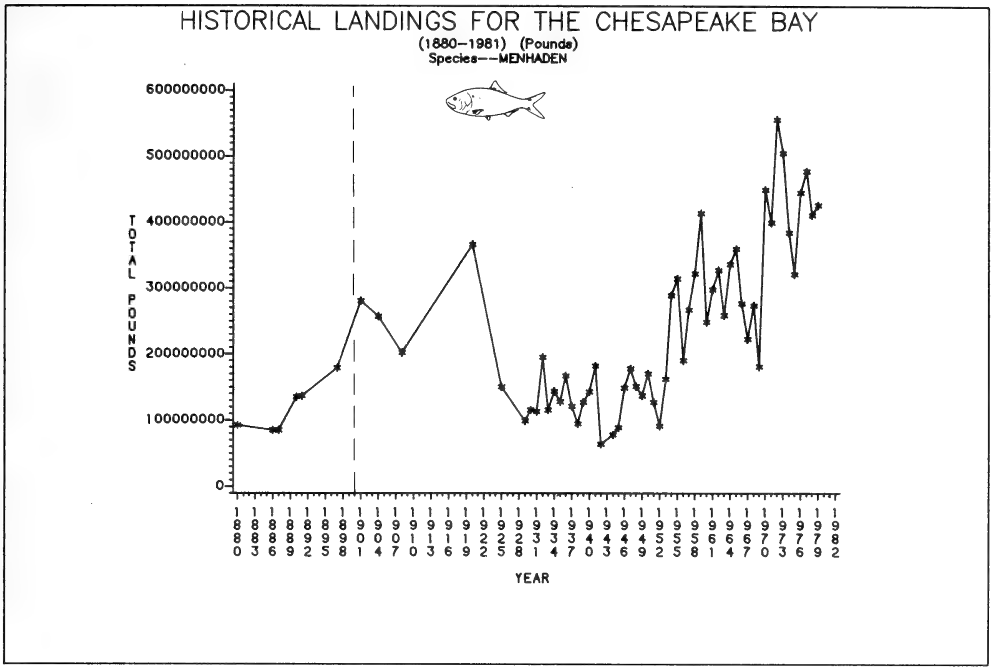

Fig. 5. Available data on landings of menhaden, *Brevoortia tyrannus,* for Chesapeake Bay, 1880–1981.

harvested in significant numbers (Fig. 4), and the capture of menhaden grew to dominate the quantities of fish landed (Fig. 5). Later catches are beyond the scope of this paper, but the perspective they provide on the 19th century patterns is important, so they are included. At the present time, shad are so scarce from the combined effects of over-fishing, damming of tributaries, and pollution that Maryland has prohibited their capture since 1980. Rock or striped bass are under complete moratorium in Maryland and severely reduced harvest in Virginia.

The Sleeping Giant

The very abundant oyster, which had been only locally utilized and sometimes regarded as starvation food by the colonists, was still harvested in relatively small quantities in the early 19th century. Shallow beds furnished perhaps 500,000 bushels per year for local consumption (Bayliff 1971). Depletion of New England beds drove opportunistic Connecticut oystermen to the Chesapeake, however—and they brought their deep-water dredges. New possibilities for both increased harvest and damage to beds immediately appeared and Virginia (1820) and Maryland (1830) outlawed the dredge. Maryland also prohibited transportation of oysters by non-Marylanders.

But the dredge remained, and a series of triphammer events changed the economy of the region and the ecology of Chesapeake Bay. The Baltimore and Ohio Railroad initiated service in 1828 and opened new potentials for distribution (Nichol 1937, Capper *et al.* 1983). Land transport of fresh, pickled, and spiced oysters was well established by 1836 (Nichol 1937). The discovery in 1840 of vast deep-water stocks in Tangier Sound, available only by dredging, encouraged a vigorous frontier industry. In 1845, the "cove" or canned and processed oyster became feasible because a method was perfected for hermetically sealing metal cans. Even the California gold rush, with its demands for portable canned goods for long voyages, added new impetus. The Baltimore oyster industry, greatest in the nation, handled the following quantities of fresh, pickled, and canned oysters (Nichol 1937):

1857 — 1,600,000 bushels
1865 — 4,000,000 bushels
1868 — 10,000,000 bushels

Dredging was legalized in 1865 and a period of unprecedented activity and violence ensued. Over 900 dredges were licensed in Maryland by 1892–93. The handwinders for raising the heavy dredges required many deck-hands and notorious practices of human exploitation existed. Wars developed at state boundaries and when dredgers invaded tonging areas (Wennersten 1981). Crisfield, Maryland, the center of the Tangier Sound oystering, was described as a "raw riotous community with saloons and brothels filled with lusty watermen."

Between 1836 and 1890, about 400,000,000 bushels of oysters were harvested in Maryland with virtually no effort to protect brood stocks, avoid destruction of small oysters, enhance reproduction, or take other protective measures despite the detailed analysis, warnings, and recommendations of scientists and surveyors (Winslow 1880, Brooks 1891, Brooks, Waddell, and Legg 1884). Natural reproduction was no longer replacing the harvest (Brooks 1893, Stevenson 1894). Oyster bars had been destroyed, enforcement of laws and regulations was weak, and the oyster wars were at their worst (Wennersten 1891).

The human effects of the labor-intensive dredge fishery for oysters were graphically and sympathetically described in an almost emotional summary on "oyster dredgers" that appears unexpectedly in a mostly prosaic volume on Maryland industrial statistics by Weeks in 1886. He states:

> "The oyster dredgers of Maryland are the most ill-conditioned body of labor I have met in the course of this inquiry. It is labor that has no home, no money—scarcely clothes. It is poor and beggardly, exposed to cold and hardship without restraint or protection of law. . . . The man who has been dredging oysters 'down on the bay' is a dilapidated specimen. . . . he is never in so good a condition as when subject to the regulations of the Baltimore City jail." (p. 67)

Weeks's interest and concern were aroused. He describes the shanghaiing of men by shipping agents at $2 a head as labor for the handwinders on the deck of the oyster boats, forced labor akin to slavery, atrocious compensation if any, and reported killing by "paying off with the boom." He developed a "synopsis of the fatalities and injuries which came to the public notice during the season of 1884–85, including men abandoned with paralysis, killings, drownings, frost-bite, jaw fracture from the dredge handle, starvation, swollen and wounded "oyster shell hands," injury from the jib-boom, and freezing to death. He vigorously and specifically recommended humane reforms.

Toward the end of the century, declines in the catch began (Fig. 6). Scientific recommendations for management were largely ignored, although measures requiring culling, use of shells to improve the setting of young oysters, and other partial corrections were adopted. Figure 6 shows the relationship of 19th century extensive and intensive exploitation to the subsequent declines. The early explosion of tonging and dredging undoubtedly removed accumulated stocks and it is impossible to make good estimates of the maximum sustainable yield under wise management and in a healthy environment. If, however, the harvest could have been maintained near 70,000,000 pounds

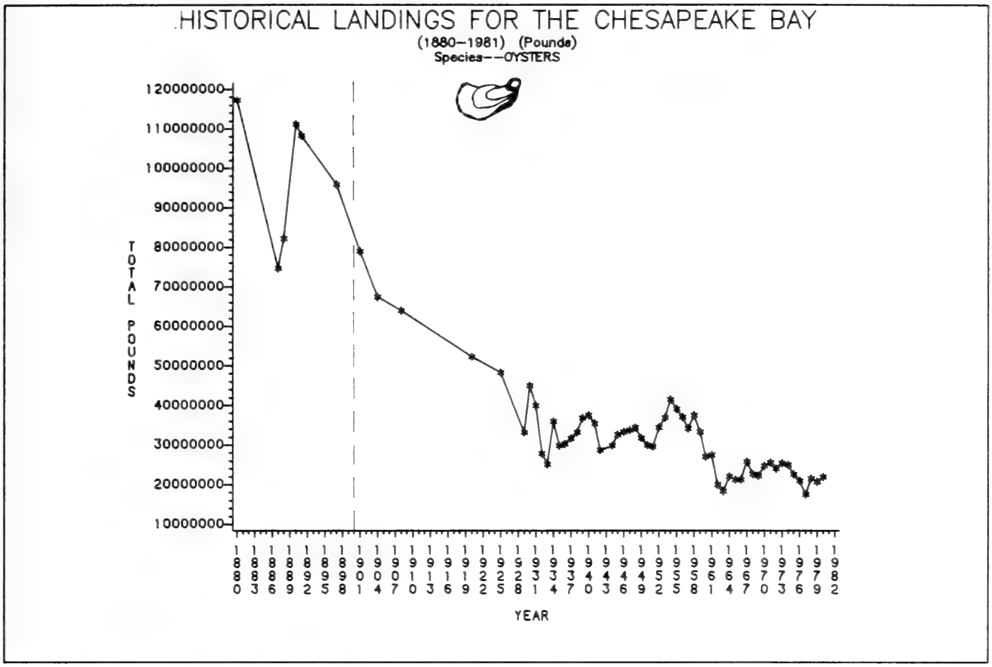

Fig. 6. Available data on landings of oyster, *Crassostrea virginica,* for Chesapeake Bay, 1880–1981.

per year (ca. 7,000,000 bushels for Maryland and Virginia combined), over 250,000,000 additional pounds of oysters would have provided food and economic benefit. At present prices for comparison, this is equivalent to at least $1,000,000,000 at the market, lost to our failures.

The sleeping giant was, in one century, discovered, overexploited, and on the path to drastic decline. The longer history has been ably summarized by Kennedy and Breisch (1983).

Crabs in Indescribable Abundance

The blue crab had been used only for local consumption, and that practice was continued through most of the 19th century. In 1873, however, the extension of a rail line to Crisfield, Maryland, near the great areas of marsh and aquatic vegetation where growing crabs concentrate to shed their shells in protection and become soft-shell crabs, stimulated the growth of a new industry. Crabs could now be caught in quantity by dipping, shed on floats, packed in ice and shipped widely—at prices like 1¢ apiece, 10¢ per dozen. In 1878, the business of catching hard shelled crabs by trotline and cooking, picking, canning and shipping the meat was begun in Hampton, Virginia (Van Engel 1962). The distinguished zoologist W. K. Brooks, who contributed much new knowledge (and some errors) about the blue crab, noted that they were to be found in "indescribable abundance." He considered questions of possible conservation measures, and predicted growing use of the resource (Brooks 1893). Figure 7 displays the increasing but small harvest from 1880–1900, and shows the later growth of the catch to a position of world dominance.

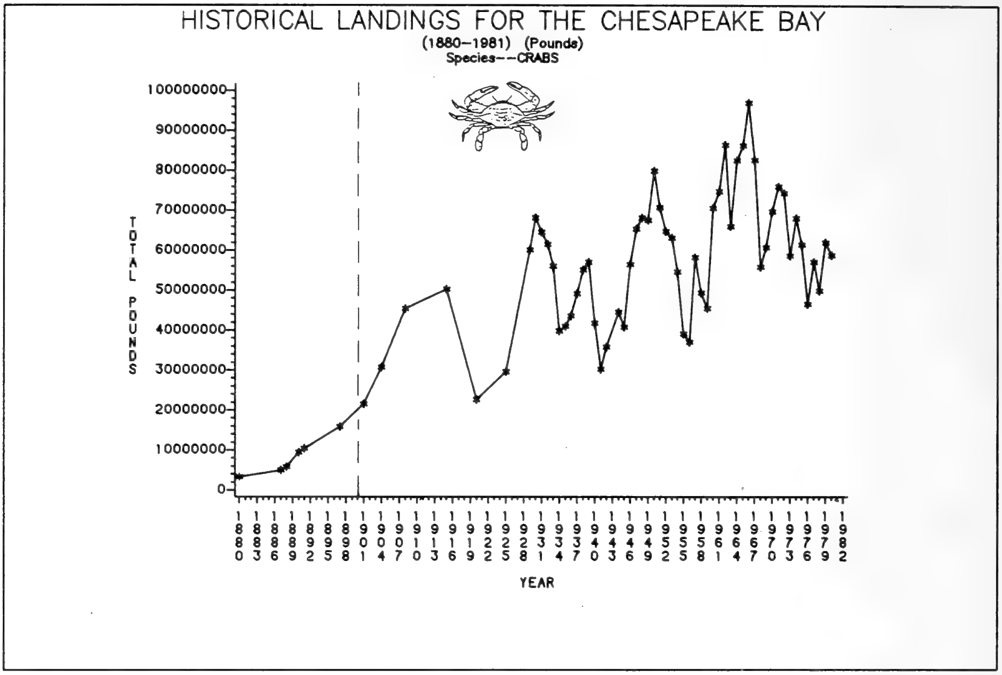

Fig. 7. Available data on landings of blue crab, *Callinectes sapidus,* for Chesapeake Bay, 1880–1981.

Millionous Multitudes of Waterfowl

Annual flights of migratory ducks and geese, which had been described in these exuberant terms by George Alsop in 1666, continued to return each autumn to the Chesapeake Bay, focus of the Atlantic Flyway of North America. Hunting for both recreation and profit flourished, especially on the rich grassy shoals known as the Susquehanna Flats at the head of the Bay. There, 4000–5000 birds per day are reported to have been harvested (Bayliff 1971). John James Audubon noted in 1840:

> "The Chesapeake Bay with its tributary streams, has from its discovery, been known as the greatest resort of waterfowl in the United States. This has depended upon the profusion of their food, which is accessible on the immense flats or shoals that are found near the mouth of the Susquehanna, along the entire length of the North-East and Elk Rivers, and on the shores of the bay and connecting streams as far south as York and James Rivers." (Audubon and Chevalier 1840–1844, cited through Meanley 1982, p. 171).

Ingenuity was applied to the practices known as "gunning," and wooden decoys, bushwhack rigs, blinds, sink-boxes, retriever dogs, and other tools were expertly applied. One estimate is that about 40,000 decoys were in use on the 25,000 acres of the Flats at the peak of ducking (McKinney 1978). Detailed data are scarce, but perhaps there was a perception by the end of the century that intensive harvesting was affecting the populations of birds, leading to the national outlawing of commercial wildfowl hunting in 1919.

The Quality of the Waters

Water quality was not examined during the 19th century by any methods that permit comparisons with modern data. Early concern was limited to sediments and wastes that might fill channels and to highly localized threats to aesthetics and health from wastes and offal. The human populations of Maryland and Virginia approximately tripled during the century, so that the direct release of human and industrial waste into waterways, the usual procedure, increased substantially, but there are no adequate records. An excellent account of changes in pollution and its management appears in "Chesapeake Waters—Pollution, Public Health and Public Opinion" by Capper, Power, and Shivers (1983), and a brief summary is pertinent.

Wastes were normally carried into waterways, usually without treatment, and the capacity of the tidal waters seemed to be infinite. Locally, obnoxious conditions existed. In Baltimore, 15,000 households poured wastes into the central creek known as Jones Falls, and gave Baltimore a position "among the greatest stenches in the world." Washington was not sewered until 1889, and then only for the transmission of wastes and run-off, not for treatment. Agricultural run-off, industrial wastes, and pollution from coal mining and other activities added to the burden.

Several dramatic events very late in the 19th century created new concern and provoked action. Yellow fever, malaria, and cholera were common and sometimes epidemic. Although water had long been recognized as a potential source of disease, the germ theory of transmission and cause was not established until just before the turn of the century—and then amid controversy and reluctance. In 1893, students in Connecticut contracted typhoid fever from eating oysters, establishing them as a vector and providing the basis for use of sewage treatment plants to protect coastal waters (Capper *et al.* 1983). The oyster was to become the most potent single stimulus for the control of domestic pollution around the Chesapeake (Cronin 1982). It is widespread, accumulates pollutants, is eaten raw, has high economic importance and has had remarkable political clout. Capper *et al.* note "Virtually all significant issues over (water) quality have had the welfare of the oyster and the oysterman as a central concern" (1983, p. 77). The 19th century efforts in pollution control were limited, however, to the recognition of dangers to human health and the first effective planning of treatment plants. Concern for the effects of pollutants on the abundance and welfare of aquatic species or on the health of the ecosystem had not yet affected public policy or practice.

The Nineteenth Century

This was an exciting period in the history of Chesapeake Bay fisheries and the stresses placed upon them. It was dramatic in the discoveries of unknown resources; innovative and inventive use of new methods of harvesting, processing, and distribution; large-scale exploitation; excessive harvests; growing pollution; and the beginnings of scientific knowledge of the fisheries and improved management. It was a century replete with lessons for the future.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 199–213, September 1986

"The Worst Oyster Season I've Ever Seen": Collecting and Interpreting Data from Watermen

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ABSTRACT

Chesapeake watermen, by virtue of their central role in the commercial fisheries, are a source for information about the Bay, past and present. Their knowledge of seafood resources, cycles and trends is gained through years of continuous observation and work experience. Watermen keep track of their observations in different ways; a few keep detailed written records while most recall the past through oral narratives. Both types of data are presented: written sources include excerpts from journals of a party-boat captain and the detailed monitoring system developed by a pound net fisherman. Oral sources consist of watermen's personal experience narratives collected through ethnographic fieldwork in southern Maryland communities. Various limitations, strengths, and the reliability of oral testimony are discussed. In interpreting such data it is possible to glean information about the Bay, but interpretations should not overlook the fact that narratives also reveal much about the watermen and the human response to specific environmental conditions in the past.

A couple of years ago, before the announcement of the rockfish ban in Maryland, the president of the Maryland Watermen's Association, Larry Simns, was musing about the future of his constituency. His comments were duly recorded in the organization's official newsletter, *The Waterman's Gazette,* and read in part: "The waterman who fishes for a living is an endangered species in Maryland, and if we lose him, we'll lose more than anyone seems to realize. What we'll lose is generations of knowledge about the fish, because the fisherman knows and cares about the fish like no one else . . . Commercial fishermen are out on the Bay all year round and they're the first to see any changes or degradation . . . Lots of people would like to see the waterman disappear entirely, but the waterman is the watchdog of the Bay. He's out there when no one else is, and he can see the degradation of the water."[1]

By now this sort of rhetoric is almost commonplace as the controversy and debate continue over how the Chesapeake's fisheries can be restored. Yet such declarations ought not to be dismissed as simply self-serving, for they do point to a valuable source for information about the Bay,

[1]Joe Valiant, "Commercial fishermen fighting extinction", *The Waterman's Gazette* Vol. 11, No. 4 (1983): 4–5.

past and present, that is largely untapped—Chesapeake watermen. This paper will discuss the range of records, both written and verbal, that are kept by watermen, focusing on the types of information that can be discovered through these sources. It will also evaluate the strengths and weaknesses of such data.

Although I am certain such information can be found all over the Bay region, my focus will be on materials in the collections of the Calvert Marine Museum in Solomons. The museum is continually on the lookout for any historical information about watermen and their work, whether it be old photographs or written documents, old gear catalogues, artifacts, and the like. All too often we learn about the existence of records, such as those kept by pound net fishermen at Flag Pond in Calvert County from about 1919 to 1955, only to find that someone—in this case, one of the fisherman's wives—deemed them unimportant, a nuisance, and had tossed them away.[2]

One fisherman's records saved from the trash heap were those kept by the late Captain Al Seigel, who had been a party boat captain for thirty-some years. He lived in Washington, D.C., but kept his boat in Southern Maryland, taking parties out of ports such as Solomons, Smith Creek, and Breezy Point. Seigel's journals consist of three volumes covering the years 1943 to 1960 and chronicle nine hundred and fifty-seven separate fishing trips. His early journal entries are very brief, consisting of the bare minimum of information, such as:

> Sunday, June 21st 1943
> Fished Tall Timber
> trolled rock pile for rock fish
> None 00
> 22 H head

It wasn't long before Seigel began recording a great deal of detail about his fishing activities. Fifteen entries later he wrote:

> Wed. Sept. 1st
> Started early morning trolling: light westerly breeze—then dead calm. Plenty gulls. Fished around Breezy Point, caught Rock & Blues. Stilled [sic] fished afternoon on stiff southerly wind: not much doing: fished around Cedar Pt.

Trolling—caught	68	Rock
	26	Blue
	1	Bonito
	3	Trouts
	12	Spots
Total	107	

An entry three years later reads:

> Wednesday, Dec. 11th, 1946
> Left Smith Cr. 8 o'clock a.m. and headed for Smith Pt. Very Foggy. Lifted around 1 p.m. Saw gulls dipping started trolling. Caught 61 rock from 3 to 17 lbs. (21 of them from 7 to 17 lbs.) Very beautiful day. Best catch of the season.

Clearly, Seigel recorded a wealth of information. He developed a format that he followed in recording weather conditions, specific areas he fished, the date and usually the time when fish were caught, the species of fish, method of fishing (whether trolling, still fishing, or chumming), the bait or lures used, and often the names of people in his party. At the end of each year he tallied the numbers and types of fish caught. For example, in 1944, he caught 894 spot; 1,197 pan rock; 690 trout; 369 large rock; and 368 hardheads for a total of 3,518 fish.

Seigel was a serious fisherman and

[2]The Calvert Marine Museum's archives contain numerous historical records pertaining to the commercial seafood industries, including business records from J. C. Lore & Sons Oyster House in Solomons; the Sollers & Dowell Company on St. Leonard's Creek; the F & H Benning Company in Galesville; and the Warren Denton Company in Broome's Island. These documents provide information about the extent of oyster harvesting and processing in specific areas and are therefore quite useful. This paper, however, will address only those records kept by individual watermen.

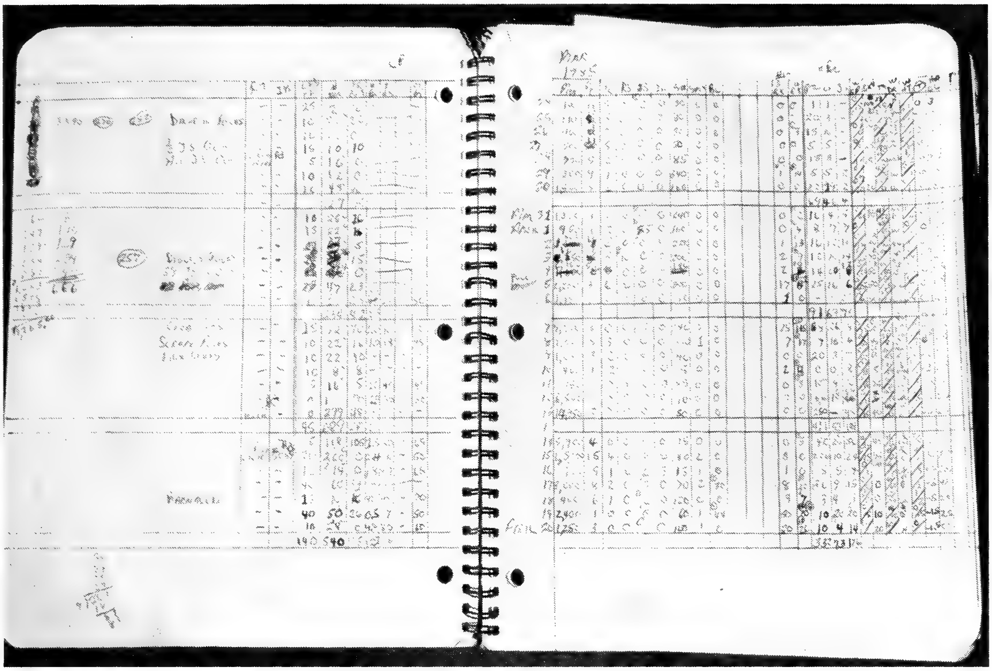

Fig. 1. Sample page from waterman Tom Courtney's journal. (Photo courtesy of Calvert Marine Museum.)

wanted to know as much as possible about where the fish were likely to be and why so that he could utilize that knowledge. Therefore he attempted to explain the results of his fishing trips by analyzing what he saw. For example:

> Thurs. Aug. 7, 1947: Left the wharf at Solomons 12:45 and headed for Cedar Pt.—then the "Hollow"—fished about an hour then decided to fish below Cove Pt.—On our way to Cove Pt. saw schools of porpoises—you know the rest—for where there are porpoises there is no fishing . . . "Where there's porpoises there is no purpose."

At the end of his entry for Saturday, Oct. 4, 1947, a day when he and his party caught 94 trout and 6 blues, Seigel added a note: "Spots seem to have left this vicinity right after the first cold snap. Last season was the same." And late in October that same year he tried to explain the habits of rockfish:

> Thurs. Nov. 27th Thanksgiving: Started from Wynne's wharf after 9 a.m. Going over the same grounds as the day previous. Did not locate any birds till late in the afternoon, and the fish seem to have dropped off. It seems to be the opinion that the rock fish are feeding during bright moonlight nights. Full moon. Total 12 rock, 1½ to 3 lbs.

Seigel's journals provide a fine record of one man's experience, one man's observations of general trends in the Bay over a seventeen-year period. Because he tended to record the same categories of information for each trip, comparisons between one year and the next can be made. Seigel used his journals for comparative purposes himself, as there is an occasional reference to a previous year, a previous trip. Although I do not know how typical

Seigel was of party-boat captains, I suspect other journals lie gathering dust in attics, garages, and boat houses throughout the Bay region.

Another record-keeper I have come across is Tom Courtney, a pound net fisherman from Ridge in St. Mary's County. Courtney sets and maintains three pound nets in the Potomac River, doing most of the work himself, although he is occasionally assisted by a mate on the water and by his father, also a waterman, on land. Courtney, by any standard, is an extraordinary waterman. He began keeping a journal in 1969, in order to keep track of certain information required by the Potomac River Fisheries Commission. In 1974, however, his journal became more detailed, as he began recording data he wanted to keep track of himself.

Courtney's current journal is a spiral notebook marked "FISH 1985". Inside he has painstakingly drawn a series of lines to mark categories of information. For the week of September 8–14, for example, he was keeping track of thirty-five different items, although earlier in the year his journal contained more columns, reflecting the greater variety of fish he harvested in spring and early summer. The thirty-five columns in September, however, recorded the following:

1. Number of bushels of crabs harvested in his crab pots
2. Number of peelers harvested in crab pots
3. Number of crab pots fished
4. Percentage of male crabs harvested
5. Pounds of menhaden harvested in pound nets
6. Pounds of trout harvested in pound nets
7. Pounds of bluefish harvested in pound nets
8. Pounds of spot harvested in pound nets
9. Pounds of croaker harvested in pound nets
10. Pounds of flounder harvested in pound nets
11. Pounds of black drum harvested in pound nets
12. Pounds of sea bass harvested in pound nets
13. Number of bushels of baitfish harvested from Point Lookout net
14. Number of bushels of baitfish harvested from Cornfield Harbor net
15. Number of bushels of baitfish harvested from Jones' Shore net
16. Number of bushels of crabs harvested in pound nets (distinct from his crab-potting operation)
17. Number of peelers harvested in pound nets
18. Number of small rockfish released
19. Number of large rockfish released

20–21. Columns devoted to two regular buyers of bait fish. Invoice numbers are recorded so that Courtney can tally the total number and cost of fish sold to them.

22. Total pounds of food fish harvested
23. Number of bushels of bait harvested (total of #13–15)
24. Number of bushels of freezer bait (This is bait he stores in a freezer; keeping track of this figure allows him to calculate the cost of electricity he uses for his bait business.)
25. Number of bushels of bait already in freezer (an inventory control measure)
26. "ST", or the number of sea turtles found in his nets
27. Weight of each sea turtle found (sea turtles are released)
28. "JF", or jelly fish; (Courtney records the abundance of jelly fish on a scale of one to ten, with one being "just a few," and two "starting to be a nuisance." Ten is "the maximum nuisance.")
29. Wave height (average)
30. Wind speed
31. "Sky", or the percentage of cloud cover
32. "T", or air temperature range
33. "W DR", or wind direction
34. Tide (a visual observation, not a measurement; a typical entry is "+.5",

indicating that the tide was one-half foot above normal)

35. Water clarity/turbidity (the depth at which Courtney can see 3-inch letter clearly)

In addition to these columns of information Courtney notes when there is a full moon or a new moon, as well as when he notices certain life forms, such as barnacles and osprey, appearing for the first time each year. And before the fishing season begins, he keeps track of when he accomplishes certain tasks having to do with setting his nets and readying his rig. For example, February and March contain entries such as: "Drove 21 poles," "tar nets," or "copper nets."

In the face of these meticulously-kept and highly-informative records of what Courtney sees and what he does, several questions come to mind: Why does Courtney bother? Does he actually use this information? How typical of his occupational group is he? Are there two hundred more like him strategically located on all the major tributaries and creeks of the Chesapeake?

Courtney, like Seigel, is primarily motivated by economic concerns: he monitors the water and keeps these records because he needs to know about the environment upon which he depends for his living. Yet Courtney's monitoring activities reflect a broader concern with the resources, not just as fish to be caught but as components of a natural system he wishes to understand. This perspective is likely an outgrowth of his years as a student at St. Mary's College, where he earned a bachelor's degree in biology in 1974, the same year he began keeping records beyond those required by the Potomac River Fisheries Commission. Courtney uses his records, frequently referring to them for information that will help him by telling him such things as when he can expect the first run of alewives, whether he is behind or ahead of where he was the previous year, or when in the past the harvests of a certain species was equally low. Courtney is not typical in that very few, if any, other watermen monitor the water and keep track of their observations as he does. He thought that other watermen might keep records of some sort but figured they would be reluctant to show them to anyone for fear of getting caught by the IRS for failing to report their true income.

Courtney and Seigel, then, represent one end of the spectrum, where a few individuals, for highly personal reasons, take the time to formally record what they see. They are in a distinct minority, yet they *do* exist and their written records provide valuable documentation of the Bay through time. Most other watermen, however, are at the other end of the spectrum. They also keep track of their observations but not in such a permanent form. More typical is Harry Huseman of Town Creek on the Patuxent, who says of his forty-year-experience on the water: "I done learned a lot, but also forgot a lot. I never write anything down. Like areas where you work, you have marks, but I keep them all up here [in his head]."[3] Huseman and other watermen in a sense "record" their experiences often by constructing oral narratives, or stories, which is the way most of us order our pasts.

Humanities scholars such as folklorist and linguist Dell Hymes have studied the use of narratives to explore and convey knowledge. He writes: "We tend to depreciate narrative as a form of knowledge, and personal narrative particularly, in contrast to other forms of discourse considered scholarly, scientific, technical or the like. This seems to me to be part of a

[3]Interview with Harry Huseman, 1981. PRP-PKR16-467. Tape citations in this paper refer to the folklife collection at the Calvert Marine Museum. The designation "PRP" indicates "Patuxent River Project," the initials following, either "PJ" or "PK", refer to the primary interviewer, Paula Johnson or Peter Kurtze, "R16" indicates that the tape is the 16th reel by the interviewer, and the last number is the location of the quotation on the tape recording and transcript.

Fig. 2. Tom Courtney fishing one of his pound nets in the Potomac River, 1982. (Calvert Marine Museum photograph by Peter Kurtze.)

general predisposition in our culture to dichotomize forms and functions of language use, and to treat one side of the dichotomy as superior, the other side as something to be disdained, discouraged, diagnosed as evidence or cause of subordinate status."[4] I would agree that there is a certain disregard for what can be called "narrative forms of evidence," on the pervasive belief that mere anecdotes are not worthy of serious attention. Yet for certain topics, such as the one at hand, narratives of watermen and other "untrained" observers are often the only form in which the data—the evidence—exists. Collecting is therefore a priority.

In 1981 the Calvert Marine Museum undertook a major ethnographic research and documentation project that involved conducting tape-recorded interviews with Patuxent River watermen, packing-house workers, boatbuilders, and lifelong residents of the region.[5] A wide range of information is contained in the resulting materials, including descriptions of gear and occupational know-how, traditional weather and fishing lore, beliefs and su-

[4]Courtney Cazden and Dell Hymes, "Narrative thinking and story-telling rights," *Keystone Folklore* Vol. 22 (1978): 21–35.

[5]The Patuxent River Folklife & Oral History Project was funded by the National Endowment for the Humanities. Its goal was to collect information about the Patuxent's fisheries for use in developing new exhibits, publications, and public programs at the museum. A team of humanities scholars representing the fields of history, folklore, and rural sociology set about collecting the "oral record," or the memories and recollections of individuals who have worked (or who are still working) on the water or in the local packing houses. The formal project lasted a year, however the collecting of oral history continued for the next three years. The resulting materials—over 100 hours of tape-recorded interviews with eighty individuals, transcriptions of the interviews, 7000 black and white negatives and as many color transparencies, plus hundreds of pages of written notes—are housed in the museum's archives and have been used in exhibits, publications, and educational programs.

perstitions, and opinions about the water business.[6] But what is of interest here are descriptive data, watermen's observations and descriptions of the Bay or Patuxent at various points in the past. The interviews contain a fair sampling of this descriptive material since the project coincided with the announcement of the Patuxent River "revitalization plan" in 1982, an issue that was at the forefront of many people's minds in Southern Maryland at the time.[7] Mention of this plan during the interviews often served as a springboard for discussion of the river in the past (as experienced and observed by the waterman) compared with what that waterman was experiencing and observing at the moment.

For example, a story told by Preston Lore, who was born in 1893 and lived near Solomons until his death in 1983, reveals the abundance of hard crabs at the turn of the century. Lore framed his comments about hard crabs by describing the ingredients for a family picnic:

> The boys and girls would go out and gonna have supper out on the river, we wouldn't carry a darn thing but the bread, vinegar, pepper and salt, probably some beer. It was always my job to catch crabs while somebody was getting up the wood and building the fire. And we always had two or three boilers, large boilers, and we filled them up with crabs. All you had to do was shove up and down the shore a little bit and there they were.[8]

Joseph Gross of Dowell described the former abundance of soft crabs in the Patuxent:

> It was two, three hundred head [people soft crabbing in the 1930s]. There were plenty crabs, they would crab around the shore 'cause they'd catch all they wanted. I caught as high as 400 crabs a mornin'. Actually, it was so many, I used to crab a place over here called Hungerford's Creek . . . A fella was buildin' boats by the name of Kennedy Grover. He had different prices on different boats, you know, [and] he had one there for $18 . . . I caught enough peelers in two days to buy that skiff . . . peelers then were 12 cents a dozen (meaning that he caught 1800 peelers in just two days).[9]

Bill Dixon of Town Creek spoke about how remarkable oyster growth used to be in the Patuxent:

> I can remember when the four German ships were tied up over here . . . four interned German ocean liners . . . I can remember when the winter froze up, can't recall the exact year but we had an awful freeze there in the late '30s, we put a mast in a sixteen-foot rowboat, put in overboard on the river, and we rowed over there and we patent tonged in a rowboat underneath the stern of these German oceanliners. We sold 'em and that was the most I ever got for oysters, that was 95 cents a bushel. That was an experience because of the heavy ice. I was nothing but a kid, so to speak, they (other watermen) all passed on . . . We had three or four boats. But that happened, them boats stayed there, there was a lot of oysters around them and I forget how many, it's documented how many thousands of bushels of oysters they scraped off the bottom of them when

[6]Several fine works using this kind of information have been produced and are, in themselves, excellent resources. See William Warner, *Beautiful Swimmers: Watermen, Crabs and the Chesapeake Bay* (Boston: Little, Brown and Co., 1976); George G. Carey, *A Faraway Time and Place* (Washington and New York: Robert B. Luce, Inc., 1971); Larry S. Chowning, *Barcat Skipper: Tales of a Tangier Island Waterman* (Centreville, MD: Tidewater Publishers, 1983).

[7]See *Draft 208 Water Quality Management Plan for the Patuxent River Basin* Maryland Department of Health and Mental Hygiene (1982).

[8]Interview with Preston Lore, 1981. PRP-PKR1.528.

[9]Interview with Joseph Gross, 1982. PRP-PKR45.382.

> they put 'em in drydock in Baltimore in the early part of World War II.[10]

Joe Scrivener, a younger man from St. Mary's County, described the first time he set a gill net:

> The first time I ever set a net I set a little piece of net about 500 feet long and the next day I had 600 pounds of rock in it, 600 and some pounds. And you just can't imagine pulling a net up and looking down and seeing fish hanging out of it. And I can still remember to this day and that was ten years ago and I guess that's what really got me hooked on it because I've fished every year since then and I've never caught any fish like I did then. I might catch 3 or 4 hundred pounds out of 6 or 7 days. That first year I started doing it you know I've set like 4 or 5 nets and I would catch like 2500 pounds of rock a night. That was hard to believe. Now I can't go down and set 15 nets and catch 100 pounds of fish.[11]

People at Broome's Island tell a cycle of stories concerning the abundance of hardheads (croaker) in the Patuxent River in the early 1950s. This, more than any other event in the region, is remembered and kept alive through oral narratives. I first heard of the tremendous run of hardheads from Clarence Sewell as we talked in his marine supply store at Broome's Island where I noticed a faded photograph of a beached shark, hung prominently near the door. When asked about the picture Sewell replied: "Claude Mister caught that shark when they were haul seining right out the mouth of the river. Now that shark weighed about 400 pounds and was eight feet long. He found that thing in the haul seine and brought it on home—towed it all the way up the river from Solomons." That image—of a man discovering a huge shark in his net and rigging up a way to tow it home so that everyone could marvel at it and, I suspect, so that he could prove this was no fish story—that image was the first of many describing the "strike of hardheads" and what that incredible run of fish meant to the community of Broome's Island.

H. C. "Duck" Elliott, another Broome's Islander, remembered that one load of hardheads took a full three days—72 hours—to get out of the net. The net was staked off in such a way that only a portion of the catch was removed at one time. One fisherman had to stand in the water up to his waist, keeping an eye on the net as it was being continually staked off and emptied. Elliott remembered handing that fisherman his meals—four of them—overboard so that he could continue monitoring the net throughout the 72-hour fishing process.

Elliott added another perspective by revealing what he personally found most exciting about that type of fishing:

> It was a lot of work but you enjoyed it because you caught so many species of fish, you never knew what you were going to have in there when you laid it out and brought it back ashore. It was interesting. Now and then we'd catch a shark or two and excite everybody . . . Sometimes the nets would be solid full of skates . . . We made a haul on the Bay that time, right around a bunch of rock and pilings. All hung up in rock and trees and Cleve [a crew member] and I were divin' down to the bottom to clear the net up 'til we get ashore and after we got it all cleared up and ashore, had all these rock and a bunch of skates in there. Cleve got stung [by the skate], like to lost his leg. He howled so loud it echoed all down the river. He still has trouble with his leg today, yessir. It's been a long time ago, that leg still bothers him.[12]

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[10]The vessels Dixon mentions were four German ocean liners seized by the United States in 1917 and interned in the lower Patuxent fro 1927 to 1940. Interview with William Dixon, 1981. PRP-PKR19.045.

[11]Interview with Joe Scrivener, 1982. PRP-PJR20.131.

[12]Interview with H. C. "Duck" Elliott, 1982. PRP-PKR43.040-052.

Fig. 3. Captain Orem Lowery (right) with fish harvested in haul seines near Broome's Island on the Patuxent River, ca. 1950. (Photo courtesy of Calvert Marine Museum.)

Clarence Sewell was in the business of hauling the fish to markets in Baltimore and Washington. He offered an explanation as to why the hardheads were so abundant in the first place:

> Then in 1950, all these fish struck in here, that was the hardheads, or croakers. And for two years there, I'm tellin you, the river was full of 'em. The onliest thing we know, the fish was probably in the Bay anyway, but it was so many, I believe you call 'em "porpoise" out here in the Bay and some of the fishermen claim that them porpoise would run after the fish, run the fish up in the river and almost ashore sometimes. The fish were trying to get away from them. If a man laid his net out and didn't catch a hundred boxes, he hadn't done anything—and that was a hundred-pound boxes, too. I think the highest

that I got in 1950, one man caught 300 and some boxes in one haul, but in 1951, one fellow, Mr. Vivian Pitcher, caught about a thousand boxes and his brother, Allen, had 817 boxes. I remember what Allen had because I bought all of his and I only taken 200 boxes of Vivian's because we were just worked to death.[13]

Elsie Elliott, another Broome's Islander, reported:

In '52 they had a big load of hardheads was landed in here and my son was on one of the seines with Orem Lowery. He was one of the crew and he missed the first big lot of it [because] he took a fishing party for my sister over there and he only made $7 that night. The rest of 'em [on the haul seine crew] made about $3,000. And they made all that money. And my son was on the next lot and he got enough to buy a car and pay for it. He wanted a car so bad . . . he got enough out of the fish at that time to buy a brand new car. It was a '52 Pontiac.[14]

Other watermen also described the abundance in terms of the economic impact upon their lives and communities. Watermen at Piney Point who had fished in the Patuxent were said to have lit their cigarettes with ten and twenty dollar bills earned from the hauls. One man recalled, "And the fishermen played cards. I remember seeing ten, twenty thousand dollars on the table at one time, yessir." His wife added, "And they played for days. My uncle played cards so long, he went blind for a few days."[15]

Leon Johnson, a former pound net fisherman at Flag Pond on Calvert County's Bay shore, talked about sturgeon, sharks, and skates he encountered in the nets:

My crew of four, we caught a big sturgeon, we hung him up in top of a building higher than this and his tail dragged the floor. And a fellow said, "If you don't know what to do with that, the boss man will lose the roe." And he thought I didn't know . . . I went over there and took an ax and chopped that far up his tail, you know, so he would bleed to save the roe. He looked at me and said, "You know something, you're from the Eastern Shore." I told him, "That's right," but I wasn't from the Eastern Shore, you know.

We went out there one mornin' and there was a big fish—a shark. They sent me back to shore to get a pistol to shoot the shark and nobody knew how to shoot it. OK. The next 2–3 weeks we caught another one. And when the shark went down and stuck his tail in the air, I wrapped around the tail like that and held it 'til they got a rope on it. That's right. They were nine or twelve foot long. And it felt just like a sheet of sandpaper. And I tied it, and we tied it right around the cleat and we worked that shark right into the boat. And they looked at me.

Skates and stingrays. They used to call me the skate man . . . we went out there and caught two and three hundred skates. They weighed 25–30 pounds. You had to be careful throwin' 'em in the boat because they had little skates attached to 'em . . . Mr. Duncan, being a religious man, we had to stop doin' that. I wanted to cut some up for crab bait and they wouldn't let me.[16]

These brief narratives are examples of the kind of information that exists in the memories of numerous individuals who have worked on the Bay and experienced its changes. But what really can we learn

[13]Interview with Clarence and "Dots" Sewell, 1982. PRP-PJR51.104.

[14]Interview with Elsie Elliott, 1982. PRP-PJR47.059.

[15]Informal interview with Francis and Connie Goddard, 1983. Field notes, Paula Johnson, 1/3/83, Calvert Marine Museum Folklife Archives.

[16]Interview with Leon Johnson, 1981. PRP-PJR11.115–141.

Fig. 4. Captain Al Seigel (second from left) and a fishing party, probably in the 1940s. (Photo courtesy of Calvert Marine Museum.)

from such narratives? What are the weaknesses and strengths of these data? How reliable are they? How useful are they? How do they contribute to our knowledge of the Bay?

It is important, of course, to recognize the limitations of oral testimony. Verbal accounts are known to be laden with sources of error, such as faulty memories and the creative process of oral tradition itself, which often includes embellishment or selective editing of details.[17] A related problem with collecting oral testimony has to do with informants tailoring their remarks to suit what they think the interviewer wants to hear or, worse yet, deliberately lying to dupe the researcher. Although there is no formula for preventing this sort of thing, there are ways to minimize the chances of it happening. Quite simply, one ought to know who he or she is talking to. Approaching a stranger and asking him about his harvest that day is not likely to yield more than a polite response which may or may not address the question. Instead, finding out who would be a good, reliable source can be accomplished by asking people one already knows—a seafood buyer, a marina owner, a boatbuilder, the Maryland Watermen's Association—for recommendations. Field techniques vary with personalities of researchers, but I have found it advantageous to have several informal conversations with an individual before requesting a tape-recorded interview. In that way, I will know a bit about who I am talking to and, vice versa, he or she will know something about me and why I want to know what I want to know. Cultivating this sort of relationship beforehand clears the way and frames the interview as something that is serious and important and is not being taken lightly

[17]See David Hufford's *The Terror That Comes in the Night: An Experience-Centered Study of Supernatural Assault Traditions* (Philadelphia: University of Pennsylvania Press, 1982). Hufford discusses the use of personal-experience narratives and the role of observation in his study of supernatural belief, acknowledging the difficulties of this approach. See also William Lynwood Montell's *Saga of Coe Ridge* (Knoxville: The University of Tennessee Press, 1970) for discussion of the use of oral narratives in historical research.

Fig. 5. Harry Shorter fishing his pound net in the Patuxent River, 1982. (Calvert Marine Museum photograph by Terry Eiler.)

by the interviewer. It is also important that people understand what will happen with the information and here I think it is a distinct advantage being a researcher from the local museum as opposed to being a biologist from the Department of Natural Resources or even a journalist. Southern Maryland watermen tend to look favorably upon the museum; many have donated artifacts and volunteered time for certain projects. Such individuals were willing to help the museum further by consenting to an interview. The fact that their memories were recorded, i.e., put in a permanent form, lessened the likelihood of deliberate duping as well. On the other hand, of course, the aspect of making testimony permanent may have discouraged some-

Fig. 6. Waterman Claude Mister shaft tonging for oysters in Patuxent River, 1982. (Calvert Marine Museum photograph by Terry Eiler.)

one from telling certain things that could have been potentially damaging or embarrassing. Here again, I found that continuing the relationship by returning for further conversations often elicited more information.

Interviewing techniques influence the type of information as well, and researchers should acknowledge that some things will not be forthcoming. Asking for exact dates is not a good strategy for they are not easily remembered or readily offered, unless the event is catastrophic or unusual. For example, years of hurricanes, bad freezes, devastation of the resources by disease, or major changes in fisheries regulations are generally recalled. Also recalled are years in which fishing activity began, a new boat acquired, a species of fish was particularly abundant or absent, or a new type of gear was first employed. Likewise, asking for statistical information about harvests is often unproductive, except with certain mathematically-minded people like Clarence Sewell, who recalled minute details about harvests thirty years ago. By and large, statistical data are not readily offered to anyone, outsiders or insiders. A researcher discovers quickly that watermen often employ the rhetorical (and occupational) strategy of understatement when asked a direct question concerning the size of their harvest, exactly where the catch was made, or other specific, quantifiable data. A waterman isn't likely to reveal how many bushels of oysters he tonged up to other watermen either, for obvious reasons of wishing to keep any source of oysters to himself. Hence the title of this paper, "The Worst Oyster Season I've Ever Seen," since this is a phrase one is likely to hear if one asks about the oyster season, regardless of what year it is.

The one type of statistical information that is usually remembered has to do not so much with nature but with commerce. Aside from individuals like Tom Courtney, the watermen's view of nature is generally not as comprehensive as that of the biologist, for the waterman's study of the natural world is directed toward human service, i.e., observing the behavior of crabs and fish for purposes of capture, and ultimately, for monetary gain.[18] Watermen remember how much they were paid for oysters or soft crabs twenty and thirty years ago as well as they remember what they were paid yesterday. Money paid out for repair of equipment or for gas to run a rig is another type of information that is readily included in oral testimony and that has been found to be fairly reliable when compared with available documentary evidence.[19]

Another limitation of oral testimony is that its time depth is relatively short. Interviews with contemporary watermen will yield a fairly good record of the local commercial fisheries, as well as personal experience narratives covering the period from after World War II to the present. Older people, such as Clarence and Gertie Biscoe of Drayden, who are both in their nineties and can still describe sailing on pungy boats to Baltimore, reveal a greater time depth. Yet the Biscoes' seventy-year memory of the Bay is still shallow compared to that uncovered by the written historical record.[20]

Despite these limitations, oral testimony is an important source to be considered in any quest for knowledge about the Chesapeake. Within narratives like those mentioned above, we can get a good sense of the abundance in the past, various cycles of seafood resources, plus information about specific species harvested and handled. And we can see in very broad terms the kinds of changes that have taken place within the lifetimes of contemporary watermen. From just these brief stories, we can glean the following information: in the 1930s the number of peeler crabs found around the shores near Solomons was tremendous and hundreds of people harvested thousands of crabs in a very short period of time; a gill netter in the lower Potomac has to set many more nets to catch far less fish now than he did ten years ago; apparently the waters of the lower Patuxent were so conducive to oyster growth between 1930 and 1940, thousands of bushels of oysters grew on the hulls of anchored ships; haul seine crews hauled tons of hardheads out of the Patuxent in the early 1950s, an unusual occurrence that coincided with porpoises in the Bay; fishermen saw a wider variety of species, including sturgeon, in the Chesapeake off Flag Pond before the 1950s. While it is beyond the scope of this paper to present a full listing of such changes noted by watermen during all of our interviews, I believe a concerted effort to do so would yield rich results. And a serious effort to collect such information from watermen throughout the Bay region would also provide a fuller record of the Bay.

Yet while informing us about the Bay, these narratives convey something else.

[18]Henry Glassie's discussion of how people in the Irish community of Ballymenone view nature guided my thinking here. See Henry Glassie, *Passing the Time in Ballymenone: Culture and History of an Ulster Community* (Philadelphia: University of Pennsylvania Press, 1982) 575–578. Other discussions of how specific cultural or occupational groups view nature can be found in Jonathan Berger and John W. Sinton, *Water, Earth, and Fire: Land Use and Environmental Planning in the New Jersey Pine Barrens* (Baltimore and London: The Johns Hopkins University Press, 1985), p. 31; Mike Brown, *The Great Lobster Chase* (Camden, ME: International Marine Publishing, 1985); and Bryce and Margaret Muir, "A Tale of Ice and Wild Dogs of the Sea," *Whole Earth Review* (July 1985): 4–12.

[19]Sources for corroboration include local newspapers and magazines; license and harvest records kept by the Department of Natural Resources; the annual reports of the Maryland Conservation Commission or Board of Natural Resources (the agency's name was changed several times); and, since the 1970s, the *Waterman's Gazette,* the official newsletter of the Maryland Watermen's Association.

[20]It should be noted that folklore, or traditional narratives, which are passed along over time and space, have a much greater time-depth (several generations) than the personal-experience narratives discussed in this paper.

They tell us much about the tellers, the individual watermen who have had a very direct relationship to (and effect upon) the Bay. In a very real sense, when we talk to watermen we are talking to the most sophisticated predator in the ecosystem. Narratives, more than any other form of evidence, reveal the human response to specific environmental conditions at various times in the past. Folklorists Lynwood Montell and Barbara Allen point out that "written records speak to the point of *what happened,* while oral sources almost invariably provide insights into how people *felt* about what happened."[21] For example, in Joe Scrivener's story cited above, we learn that he caught six hundred pounds of rockfish the first time he set his gill net. Yet in telling this, he also describes the impact that experience had on him, "you just can't imagine pulling a net up and looking down and seeing fish hanging out of it. And I can still remember to this day and that was ten years ago and I guess that's what really got me hooked on it because I've fished every year since then and I've never caught any fish like I did then."[22]

Likewise with the Broome's Island cycle of hardhead tales. The abundance extolled by the storytellers can be confirmed with statistics from the Chesapeake Biological Laboratory in Solomons which indicate that in 1952, 93,703 pounds of croaker were harvested with haul seines in the Patuxent River. But Clarence and Dots Sewell, Duck Elliott, Claude Mister, Elsie Elliott, and others from Broome's Island tell us what those 93,000 pounds of hardheads meant to them and to their community. Of course, the harvests had an economic impact, evidenced by the purchase of a '52 Pontiac after one haul of fish, but there was another dimension to the experience. This era in the recent history of the community is what Broome's Islanders invariably choose to talk about when conversation turns to the river or their community. It is collectively remembered as a time when everyone worked together, sharing the labor and the benefits of labor. And that is how they prefer to identify themselves—as participants, neighbors, people connected. It is true that the stories tell us about a natural phenomenon that can be verified with fishery statistics, but they also tell us a great deal about the attitudes, values, and perspectives of the people who occupied (and continue to do so) a certain niche in the web of Bay life.

Watermen's narratives—and their written records—comprise a unique body of knowledge that is still largely scattered and ephemeral, but which warrants systematic collection and interpretation. By describing how their own circumstances have changed through the years, what they noticed about environmental cycles and trends and how they responded, watermen provide clues about larger changes in the Bay. Certainly our understanding of the Bay's history is enhanced by the experiences of those who are not only watchdogs of the Bay, but active, dynamic participants in the Chesapeake ecosystem.

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[21]Barbara Allen and William Lynwood Montell, *From Memory to History: Using Oral Sources in Local Historical Research.* (Nashville: The American Association for State and Local History, 1981), pp. 20–21.

[22]Interview with Joe Scrivener. 1982. PRP-PJR20.131.

Journal of the Washington Academy of Sciences,
Volume 76, Number 3, Pages 214–217, September 1986

Looking Backward to the Future

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This seminar closes the last of seven symposia on estuaries sponsored by the NOAA Estuarine Programs Office during 1985. To top it off, a few weeks ago, I refused an invitation from mainland China to join a group of "experts" to review extraordinary problems with massive estuaries in their tens of millions of land-water acres.

The recent upsurge of interest in estuaries would warrant a separate symposium. I resist philosophizing thereon, although its relevance to my assignment will appear in my comments.

The program for the seminar reported in this book was apparently designed as a kind of "wrap-up" of the previous six conferences. This is the task I have been assigned and hence my paper should be read with reference to the papers printed elsewhere in this volume. Detailed summaries of these contributions are not included here because of their large number. The papers supplement each other and present an impressive and fascinating picture of past complex behavior. The time span of millions of years will provide consternation to many officials who encounter this document and who seek simple verities.

The historical review discloses the natural consequences of geological, climatic, and meteorologic phenomena—and, in more recent thousands of years, the impact of man and his culture upon the bays of the United States.

Concommitantly, similar long-term explorations have been carried out in other parts of the world. They give further evidence of global interest in the long past, perhaps to supply some clues as to how to meet the problems of the present.

Among these are the discovery of the totally unexpected behavior of ecosystems of deep-ocean vents. Archaeological sites in the Vasco-Contabrian Region of Spain have yielded detailed records of changes in the human condition from about 125,000 years ago until the adoption less than 6,000 years ago of food production.

An equally timely example is in the finding of geophysicists analyzing old surveying records in the eastern United States. They may be able to pinpoint sites of possible future earthquakes in this region. The U.S. Geological Survey discovered evidence that during the last 100 years stress has been concentrating in the upper earth crust north of New York City. Western Long Island seemed to be accumulating stress several times faster than in most parts of the dangerous San Andreas fault in California.

This rehearsal emphasizes the commonality of purpose pervading the activities of geologists, archaeologists, anthropologists, and engineers. The search of the past to disclose appropriate action for the future is not only exciting but promises to be rewarding.

What does the evidence appear to disclose? Primarily, it makes abundantly clear that estuarial behaviors must be sharply distinguished between those due to natural forces and those introduced by man. Nature's dynamic reactions are demonstrably powerful in contrast with man's more complex identification and control of impacts.

The records indicate contradictions to some of the principles and practices of today, already embedded in the views of distinguished practitioners.

The phenomenon of anoxia is an interesting case in point. Many environmentalists are convinced that this event ensues largely because of excessive input of phosphorus and nitrogen and consequent eutrophication. Other investigators warn that anoxia is most frequently the result, seasonally, of dynamic physical events, such as winds, wave actions, and temperature, and only secondarily by familar nutrient overloads. These nutrients currently hold the stage as major culprits—as well as major dollars for elimination. Experienced investigators insist that legislative prohibition on the use of phosphate detergents is the key to estuary, lake and impoundment salvation, while nitrogen may take over in more saline waters.

The letter inviting me to present my comments had an attachment. It listed sixteen questions headed "Explain function of focusing on history to guide future." The designer of the program had well in mind the current demand on "historians" to provide such guidance—pressing them to join the futurologist's cult!

I need no hint, however, to press the speakers ultimately to answer, in the parlance of the street, "so what?" The sixteen questions should find a prominent place in the final documentation of this symposium. They rehearse the burning questions of today, as history has revealed or failed to reveal helpful answers.

The bald question generates the important issue: what do we want of the Chesapeake Bay? A source of oysters, crabs, rock fish, clams, fish, or grasses, forests, sports, esthetic environs, or all of these? Some say the historical record rests upon too limited sampling frequency and geographical coverage to warrant total acceptance of its findings.

A more critical and unavoidable deficiency is that little or nothing is discernible as to political commitment, scientific uncertainty, or community behavior. These constraints, coupled with a major deficiency of skilled manpower, determine what we do or may do in the foreseeable future. The recapture of the estuaries is designed to reduce, at least, the inevitable rate of degradation—easy to state, difficult to implement.

The existence of people is recognizably a nuisance. Their presence and multiplication are probable for a long time ahead. Their activities may be destructive, illogical, perverse, and selfish. One must assume, however, these behaviors are susceptible to change, provided we have learned how to translate scientific-technologic findings of the past and of the thousands of recent data emanating from the Chesapeake, Narragansett, San Francisco, and lesser estuaries throughout the United States.

We still lack an agreed scientific monograph that integrates discrete research data into a total picture, from which the public, officialdom, and scientist may design acceptable action programs. In its absence, we have the travail wherein the scientist takes refuge in requesting a larger budget for research. We do not understand the behavior of the Bay and continuing basic research must go forward—even though too often downgraded by budget makers.

Once in a while, but rarely, does someone whisper that significant recapture of productivity will occur only with a fundamental and courageous change in public policy, more than in scientific disclosures. The time may be ripe and the symposium summary may well recognize that, in addition to all that history teaches, the public will and desire may disclose the key. The public has yet to demonstrate its wishes to change fundamental policy as to the management of the Bay. None of the papers emphasize that no farm would survive the interesting and peculiar mode of operation that the State of Maryland has permitted in this underwater farm for more than a century. Concealed throughout the discussions, only the lament of Paula Johnson is a reminder of our delinquency!

I cannot close without noting a few salient approaches to maintaining the "health" of this remarkable underwater farm. Undoubtedly, reduction of sediment discharge into the Bay is an agreed "must." It is one of the few prescriptions apparently acceptable to all diagnosticians.

Sedimentation unfortunately harbors nutrient generation. Sediment resuspension further releases organics and changes metal patterns. The particles settled in the bottom keep their surface load of phosphorus in the sink. In some instances nearly 60 per cent of the phosphorus absorbed to these particles remains mobile and thus represent a potential source for internal phosphorus loading.

Phosphorus and nitrogen do not have unanimity of acceptance as enviromental problems, either singly or jointly. Their elimination or reduction require different measures of action. It would be the part of wisdom to recognize the difference and press rapidly toward scientific clarification of impact. Both nutrients are probable culprits—as well as minimum necessities for ecologic survival.

Designers of waste water treatment should look more often to N/P ratios to determine when each is the limiting parameter to growth of organisms. Recognition is belated of the use of aquatic plants in bio-systems to ameliorate waste waters. In some instances most of the N and P accumulates in the harvestable portion of the plants. This method was used in the field some 10 years ago in Hungary. As always, the choice must be site specific and management must be of high order.

Parenthetically, the use of macrophytes, as effective and cheaper for purifying waters, is being pursued in developing countries, where conventional orthodox methods are too expensive to be used.

Control of periodic excessive algae growth remains less than satisfactory. Regulators may have learned by now not to over-promise elimination. Too many sources of such growths remain in the Bay to warrant guarantees of ultimate total prevention.

A similar warning pertains to the desire and hope of eliminating metals. The list is long and many people aim to remove them at source. The dilemma in this case is that more than a few have positive values in the protection of human health and of the ecosystem itself. Examples are chromium, zinc, copper, molybdenum, phosphorus, and boron. As a matter of fact, the periodic table contains a series of elements appearing in our streams that are toxic in high concentrations but essential to life in low ones. Selenium is a striking example of this dichotomy. Standards for this element in water have been virtually close to zero, because cattle died from consuming grasses high in selenium. A dramatic example of soil geochemistry impact has come out of China in the past few years. A number of unusual diseases were epidemic around Keshan in North East China, and in a wide belt into South West China. Occurrences were manifest in live stock and humans. In the latter the diseases became known as Keshan disease, linked to the unusually low selenium levels in the local soil. The urban population obtained sufficient selenium from foodstuffs transported in. Rural peasants ate locally-grown crops low in selenium and suffered high mortality. Provision weekly of dietary supplement of selenium has resulted in the disappearance of the disease.

One more disturbing caution, familiar to our hosts, needs to be registered—the threat of the "Greenhouse Effect." Roger Revelle, in San Diego on November 12, predicted that, within the next two or three decades, precipitation and runoff would materially decline, ocean levels would rise, ground water salinities would increase, and temperatures would rise.

His positive views are not yet generally supported. The International Advisory Committee on Tides and Mean Sea Level comments on its recent Report* that:

> "On the surface . . . the lines of thought seem speculative but straight forward. A closer examination of the attendant physical arguments reveals a host of very serious problems that make estimates of sea level change and this interpretation highly uncertain."

The Symposium today is exciting in its implications. The papers are beginning to answer a series of questions posed in a recent flier from the University of Rhode Island. "What's the connection between Narragansett Bay and the Guayaquil Estuary in Ecuador? Or between Guayaquil and Columbo in Sri Lanka? Or between Sri Lanka and Indonesia or Thailand? The ocean. And the common heritage of its riches, both on and off shore."

It has been estimated that 70 per cent of the world's population lives along the coastline, while 30 per cent is inland. If these ecosystems are efficiently managed, their abundant values may be captured. If not, the penalties may be irreversible to man and environment. Dr. Mountford's opening remarks provide a fitting closure to my so-called Summary. He points out, with admirable brevity, the questions emanating from the contributions. Of even greater importance are his deep-seated hopes of profiting from history's disclosures.

In his closing words:

> "Can we extend our vision back through time to gain a meaningful perspective? Will we be able to share technology among these several sciences enough to have confidence in those insights? Can we define, in some useful sense, what Chesapeake Bay, and other troubled habitats on this planet, really were like in the past?"

Acknowledgements

I am greatly indebted to all the speakers for prompt delivery of abstracts of their papers. They have been inspiring in content and challenging in issues. I pay particular thanks to Grace Brush who has given me an opportunity for several valuable discussions—due to the happy coincidence that our offices are in the same building.

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*Changes in Relative Mean Sea Level, Transactions American Geophysical Union, EOS, November 5, 1985.

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VOLUME 76
Number 4
December, 1986

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly
at Washington, D.C.

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Washington Academy of Sciences

Founded in 1898

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Commentary

The Role of Courts in Environmental Decision-Making

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In this paper, I shall first discuss some basic differences between law and science, then proceed to consideration of the manner in which environmental decisions are made in the first instance by administrative agencies and the courts, and finally discuss apellate review of these decisions in the federal courts.

Law is a pervasive element in our societal and institutional structure, and it establishes the general framework within which all activities and endeavors, including science are conducted. There are, however, some important differences between the law and the science cultures, and a failure to understand these differences often impairs communication and collaboration between the two.

Science is concerned primarily with unlocking the secrets of nature through the acquisition of knowledge. Its primary objective is to seek the truth. Nothing is accepted as valid by science for which validity has not been demonstrated; and even where something is accepted as valid, it is recognized that its continuing validity is dependent upon its not being demonstrated to be invalid. Science rests upon a solid foundation of principles that have gained universal acceptance, or at least acceptance by overwhelming consensus of scientists.

Law, on the other hand, is based on verbal formulations, and its content varies with the meaning given to particular words from time to time by those who interpret and implement the law. Moreover, the law—at least the Anglo-American version—is not driven by a quest for objective truth.

Statutory law more often than not is based on emotion, politics, and compromise rather than on coherent principles that objective experts would regard as valid. Indeed, legislatures frequently enact statutes that are deliberately ambiguous so that the legislators can give the impression of having accomplished something while avoiding coming to grips with thorny issues by bucking these issues to the agencies or the courts that will implement the legislation.[1]

The agencies and courts that interpret, implement, and enforce the law rely on the adversary system. Each party in the proceeding presents evidence and arguments that will support its position. The parties, even when a party is the government or a regulatory agency, present their positions in the strongest possible form, usually overstating the case. Only rarely will the unadulterated truth, recognizable as such by the tribunal, be presented to it. Moreover, the tribunal will only rarely be expert in scientific or technical aspects of the case, but it must nevertheless decide among the competing facts and contentions.

Given this general approach to lawmaking in the United States, it is too much to expect that scientifically or objectively correct decisions will be reached in environmental litigation. Indeed, it is not the function of the law in a democratic society such as ours to make correct decisions. Its function is to resolve conflict in the optimum manner, and optimum resolution of a dispute may require that something be stated to be the truth that is not in fact the truth. We all know, for example, that one who is convicted of murder may not in fact have murdered, and that acquittal does not mean that the defendant did not in fact do the foul deed. Whether objectively correct or not, the court's judgment presumably represents the best decision that can be fairly rendered in that case.

Lawyers accept the legal system as pragmatic, albeit imperfect. We aspire to improve the system so that it will produce laws and decisions that are objectively more correct. At the same time, we recognize that toleration of erroneous results lends considerable flexibility to the legal system and facilitates the kinds of accommodation that are necessary to ensure public acceptance of public-policy decisions in a pluralistic democratic society. A quest for truth and correct decisions in the decision-making process, if pursued to the limit, would produce the orthodoxy of a "big brother" who would define and effectuate TRUTH. We also recognize that in our form of government, the process of reaching decisions is more important that the correctness of the decisions reached. It is for this reason that we rely upon the adversary process which has the conspicuous virtue of giving every interested party the opportunity to present the strongest possible case for his/her position to a tribunal that knows sufficiently little about the subject matter that it will presumably render an impartial and fair decision.

I turn now to the specific subject of environmental decision-making. Courts become involved in this process in one of several ways that I shall attempt to describe briefly, confining my description, for purposes of simplicity, to the federal courts. The easiest case to describe is that of litigation in which a plaintiff brings suit against a defendant and asks the court to restrain the defendant's conduct on the ground that it involves a serious environmental insult, and/or seeks to recover money damages for injuries resulting from the insult. This is the easiest case because there is really little to be said that was not said in my earlier description of the legal culture. Suffice it to say at this point, the issues of whether there was in fact an environmental insult and if so the resulting quantum of injury are decided by a judge or jury who almost certainly have no particular knowledge of the relevant science. The question whether the law, i.e., common or statutory, provides a remedy is decided by the judge, who also instructs the jury as to the legal framework for its consideration of the evidence. Obviously, this role provides the judge with considerable latitude to shape the ultimate outcome of the suit.

In some such litigation the Government or an agency of the Government may be either the plaintiff or the defendant. If the former, the typical case involves the effort of the Government or agency to enforce a particular statute where the defendant is alleged to be in violation of it. On the other hand, if the Government or agency is the defendant, the typical case involves the complaint that a particular action that has been taken or is proposed to be taken would be injurious to the environment. A good example of this is *Allen v. United States.*[2]

Allen was a suit by 1,192 plaintiffs who alleged serious loss due to cancer or leukemia induced by fallout from nuclear weapons testing in Nevada from 1951 to 1963. The trial took 13 weeks, and there were 98 witnesses, some of whom, to quote the judge, were "prestigious, gifted, and historic figures—and, I might add, highly opinionated."[3] In addition to 7000 pages of testimony, there were almost 1700 documentary exhibits, some newly declassified, amounting to more than 54,000 printed pages.[4] The case involved, among other questions, "the method and quantum of proof of the cause in fact of claimed biological injuries."[5]

Writing after his decision in the case, Judge Jenkins offered these instructive observations:

> No matter how complex the factual footing might be, the judicial determination of facts in a complex case is indistinguishable from fact-finding in other cases. Thus the fallout opinion speaks in terms of common concepts—of natural and probable consequences, of substantial factors, and of things more likely to occur than not.[6]
>
> We are not required . . . to find beyond a reasonable doubt. Rather, it is the judicial resolution of disputes with which we are concerned. In the pragmatic world of "fact," the court passes judgment on the probable. Dispute resolution demands rational decision-making, not perfect knowledge. Perfect knowledge does not require judgment, only description.[7]
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> ******
>
> . . . in complex litigation involving elusive and perhaps contested phenomena of nature, the advocate and the judge must transcend the traditional jargon of the law and become conversant in the language of risk assessment . . . . [and] make greater use of the information base available, whether through research in the library or through the help of experts.[8]
>
> Scientific evidence must be examined with the same skepticism as any other evidence. The court must . . . bring to dispute resolution the critical eye and the element of objectivity so often absent from competing scientific viewpoints.[9]
>
> ******
>
> . . . . In the courtroom, risk is far more than a question of physical process or mathematical probability. One must add people and values and social consequences to the equation. Moreover, the court is concerned not only with the specific persons seeking help, but also with the harm to society and to social values in general. . . .[10]
>
> Let me issue a word of caution about being spoon-fed by experts; this can be a risky business. . . . One of the shocks of growing up . . . is to discover how human scientists can be; they can be opinionated and downright quarrelsome, and can cling tenaciously to ideas in which they have a vested interest. Let me add quickly that not all scientists fit this description.[11]

I have quoted at length from Judge Jenkins' thoughtful comments because they reflect my earlier discussion on the legal culture. Although Judge Jenkins does not explicitly address this point, he tells us implicitly that scientific quantifications of risk, and presumably of benefit, are not controlling in the courts.

In this connection, it is important to recognize that our legal culture has always had an interest in risk-benefit assessment. In the law of torts, for example, we ask whether a defendant's conduct constituted an "unreasonable risk" measured by whether the "magnitude of the risk outweighs the value which the law attaches to the conduct which involves it."[12] In determining the magnitude of the risk, we consider the probability, magnitude, and extent of harm that may result;[13] and in determining the utility (i.e., benefits) of the conduct, we consider whether comparable social interests can be adequately advanced by alternative, less dangerous conduct.[14] Moreover, when we look at the judicial decisions applying these principles, we see no attempt at quantification of the various parameters. Instead, the courts perform the balancing operation *qualitatively* on the basis of an amorphous "community standard" derived from the wisdom, experience, and the commonsense of the judges and juries.[15] In other words, to use the words of Judge Jenkins, "people and values and social consequences" are factored into whatever quantitative evidence may be available.[16]

As the U.S. Court of Appeals for the District of Columbia Circuit put it in *Industrial Union Dept., AFL-CIO v. Hodgson*, "when insufficient data is presently available to make a fully informed factual determination . . . . decision making must . . . depend to a greater extent upon policy judgments and less upon purely factual analysis."[17] In the same vein, the court indicated that the relative weighting of probability and magnitude of harm is a matter for judgment by the decisionmaker and does not turn on purely factual analysis.[18]

In short, the judicial process is not one in which science and scientists are controlling, and many scientists will understandably be bewildered and unhappy about the manner in which the courts seemingly defy science and its analyses as decisions are made in individual cases. An example of this discomfort is found in a 1973 address by Dr. Philip Handler, then President of the National Academy of Sciences, in which he commented on the EPA's DDT decision, Dr. Handler's concerns would be equally applicable to a judicial trial involving a similar issue:

> I have undergone the masochistic exercise of reading a considerable part of those hundreds of pages of testimony which were taken by the hearing examiner [who would now be called an "administrative law judge"] who "examined DDT" and then made his recommendations to the administrator of the Environmental Protection Agency. I say "masochistic" quite deliberately. Two-thirds of the so-called "scientific evidence" that I read could not have found acceptance by the editorial board of a reputable scientific journal.
>
> The situation was summed up, I thought, in the remarkable words of the administrator of EPA in the decision statement in which DDT was effectively banned for most purposes. As close as I can recall it, he said "DDT constitutes an unquantifiable hazard of uncertain nature." . . . . I am not disagreeing with the decision itself. It is the basis for decision making, the inadequacy of the data, which I found so very troublesome, I still do. . . ."[19]

It is clear that Dr. Handler was unable to accept the legal culture.

Let me turn now to the appellate role of the courts, which in federal environmental cases, means primarily the United States Courts of Appeal and the Supreme Court. In order not to prolong my discussion unduly, I shall confine my remarks to judicial review of decisions of federal regulatory agencies such as the Environmental Protection Agency and the Nuclear Regulatory Commission. These regulatory actions may be in the form of an order promulgating rules and regulations of general applicability, or in the form of an administrative decision involving specific parties. In either case, the proceeding before the administrative agency would be subject to the provisions of the Administrative Procedure Act.[20] In rule-making proceedings, any interested person may participate, most frequently through the opportunity to submit written comments, but sometimes as a party in an administrative hearing where a hearing is required by statute or where the agency decides to have one. Such hearings are generally more informal, without many of the trappings of an adversary proceeding, than litigation in the courts. Where, however, a statute requires an adjudicatory hearing, it resembles a judicial trial. Decisions by regulatory agencies are generally subject to review by a United States Court of Appeals, and to further review by the Supreme Court.

Each of the regulatory agencies is a creature of the Congress and must conduct its activities in conformance with the particular statutory provisions to which it is subject in the case before it. Each of the statutes contains in greater or lesser detail specific findings that must be made as a predicate for rules to be promulgated or decisions to be made by the regulatory body. There are also in each statute specified procedures that must be followed by the agency in adopting rules or making decisions. No two statutes have identical, or for the most part even similar, criteria or procedures. Even within a single agency such as EPA, which administers a number of statutes such as those regulating air quality, water quality, fungicides, insecticides, rodenticides, automobile emissions, toxic substances, hazardous wastes, etc., there are wide variations in the criteria and procedures. These are attributable not only to the perceived differences in the subject matter to be regulated, but also to the particular time at which the legislation was considered, the prevailing political climate at the time, the particular vested interests that would be affected, and the political clout of those interests. Sometimes, the statutory criteria are highly ambiguous, frequently, because the particular matter was politically difficult for the Congress to resolve, so that in effect the issue was handed to the agency and the courts for resolution.[21]

Thus, the legal significance of the evidence developed in the agency proceeding is determined in the first instance by the agency's interpretation of the statute. In some cases, the statutory criteria reflect the Congress' own risk-benefit assessment and produces a result that many scientists would regard as "bad science." The Delaney amendment to the Chemical Food Additives Act of 1958,[22] which prohibits the use in food of any chemical known to produce cancer in animals is a good example of this.

Let me turn now to the question of judicial review by the courts of environmental decisions made by regulatory agencies. At the outset, it must be emphasized that it is not a proper function of the court to review the evidence *de novo* to determine whether the decisions made by the regulatory agency were correct. Rather, the functions of the court are limited to ensuring that the decisions under review have been made in accordance with applicable statutes, that they are not arbitrary or capricious, and that they are supported by "substantial evidence." In considering conformity with the applicable statutes, the court is concerned with both substantive and procedural issues. On the substantive side, the court looks into the question whether the agency's action was based on the statutory criteria for the action and whether the requisite findings were made. With respect to procedure, the question is whether the agency reached its decision and action in accordance with applicable statutory requirements. Parenthetically, it should also be noted that the court may also inquire into whether the agency compiled with the substantive criteria and procedural requirements set forth in its own rules and regulations.

Compliance with procedural requirements is particularly important from the standpoint of appellate review of agency actions. These requirements are set forth in the basic regulatory statute such as the Clean Air Act, the Toxic Substances Act, or the Atomic Energy Act; in the Administrative Procedure Act; and of great importance in recent years, the National Environmental Policy Act. In addition, however, the courts, particularly the U.S. Court of Appeals for the District of Columbia, have attempted to fashion procedural requirements of their own. For example, in a series of decisions that court has insisted upon "principled decision-making" by the regulatory agencies. This requires "administrative officers to articulate the standards and principles that govern their discretionary decisions in as much detail as possible."[23]

The judicial decisions that invalidate agency actions on procedural grounds may reflect an implicit disagreement with the substantive position reached by the agency. Indeed, Judge Wilkey of the D.C. Circuit openly accused his colleagues of using the National Environmental Policy Act "to delay the development of important energy sources."[24]

In terms of explicit review of the substance of the agency's action, the courts are required to sustain the agency's action if there is "Substantial evidence" supporting it. "Substantial evidence" does not mean the weight or preponderance of the evidence, but only that there was enough reasonable evidence to support the agency's findings. Thus, the court cannot invalidate the action merely because it disagrees with it or believes it was incorrect. It is not necessary that the evidence before the agency be certain. As the D.C. Circuit stated in one case in which it upheld a decision by the EPA Administrator in which there was a "great mass of often inconsistent evidence," the "evidence is substantial enough to support the conclusions of the administrator, although it possibly might support the contrary conclusions as well."[25]

I return to somewhere in the vicinity of where I began in my discussion of the legal culture. The judicial system relevant to environmental decision-making simply is not equipped to, and is not expected to, produce objectively correct decisions. It is, however, expected to guard against decisions that are arbitrary, capricious, or, indeed, "far out." A useful way to look at the process is as part of the political system. The decision-making power of regulatory agencies is constrained in three ways. The members of Congress who were instrumental in enacting the environmental legislation in the first place usually have a paternalistic interest in having the legislation implemented in the general manner they intended. A "far out" action by the agency is likely to produce some kind of a formal legislative action such as a corrective amendment to the statute or informal action such as strong public rebukes, hostile hearings, appropriation cuts, or the like.

A second constraint, also political in nature, is the fact that the agency is subject to the influence of the President in a number of respects. Even where the agency is an "independent regulatory agency" which Congress established with safeguards to insulate it from control by the President, he may nevertheless be able to exercise some control through the budgetary process and his/her power to nominate, and in some cases remove, the agency heads. The agency heads cannot, therefore, stray too far from the President's political desires lest they jeopardize prospects for their reappointment and advancement in the government service.

The third constraint is the likelihood of judicial action overturning the regulatory decision.

Reviewing courts are subject to similar constraints: the possibility of corrective legislation and of reversal by the Supreme Court. Although they are much less politically vulnerable than regulatory agencies, they too must reach their decisions with one eye focused on political reality.

Thus it is concluded that the courts' role in environmental decision-making is quite limited and tends to center more upon procedural than substantive issues. Because the courts have no scientific competence, contestants in environmental decision-making who come before the courts are compelled to do so in the vocabulary of ordinary discourse; to try to reduce scientific information to language that can be comprehended by laymen (even though the courts and laymen may often in fact erroneously comprehend). It must be remembered that in environmental litigation, the basic issues involve benefits and risks to the public, the assignment and allocation of which is essentially a political function. Even though such issues are decided in the first instance in the legislative process, the role of the courts is essentially to assist in the resolution of disputes that arise over the application of statutes in particular situations. In this sense, therefore, the role of the courts is adjunctive to and supportive of the democraic political process. We cannot, therefore, expect that the environmental decisions of the courts will be regarded as scientifically acceptable, let alone scientifically correct.

Some will find this conclusion uncomfortably pessimistic. Although everyone will, at least on a moment's reflection, agree that the legislative process is essentially political, and that it frequently produces strange or seemingly irrational results, we seem to expect better results from our courts, and by and large I think we get them. But why should we expect a more objectively correct decision on a scientific issue from a court that is interpreting and applying an environmental statute that was enacted by Congress through the essence of the political process with little attempt to ensure that the statutory standards reflect good or objectively correct science?

References Cited

1. See the dissenting opinion of Justice Rehnquist in *American Textile Manufacturers, Inc. v. Donovan*, 452 U.S. 490, 543–48 (1981).
2. 583 F. Supp. 247 (D. Utah, 1984).
3. These comments, and those quoted below, were made by Judge Bruce S. Jenkins, before whom the case was tried, in a talk at the Fourteenth Annual Conference on the Environment sponsored by the ABA's Standing Committee on Environmental Law on May 17–18, 1985. See American Bar Association Standing Committee on Environmental Law, *Dealing With Risk: The Courts, the Agencies, and Congress* 1 (1985).
4. *Ibid.*
5. *Allen v. United States*, *supra* at 257–58.
6. **Jenkins,** *op. cit. supra* n.3, at 2.
7. *Id.*, at 2–3.
8. *Ibid.*
9. *Ibid.*
10. *Id.*, at 4.
11. *Id.*, at 3.
12. Restatement of the Law of Torts, 2d, §291.
13. *Id.*, §293.
14. *Id.*, §292.
15. See, for example, *Osborn v. Montgomery*, 203 Wisc. 233, 234 N.W. 372 (1934); *United States v. Carroll Towing Co.*, 159 F.2d 169 (2nd Cir. 1947).
16. **Jenkins,** *op cit. supra* n.3., at 4.
17. 499 F. 2d 467, 474; see also *Ethyl Corp v. Costle*, 541 F.2d. 1, 26–29. (1976).
18. *Ibid.*
19. National Academy of Sciences, *How Safe is Safe? The Design of Policy on Drugs and Food Additives,* 1, 2–3 (1974). Dr. Handler's comments were made in his remarks opening the forum.
20. 5 U.S.C.A. §551, et seq.
21. See n. 1, supra, and accompanying text.
22. 21 U.S.C.A. §348(c)(3)(A).
23. *Environmental Defense Fund v. Ruckelshaus,* 439 F. 2d 584, 598 (1971).
24. Dissenting opinion in *People Against Nuclear Energy v. Nuclear Regulatory Commission,* 678 F. 2d 222, 237–238 (1982).
25. *Environmental Defense Fund v. EPA,* 489 F. 2d 1247, 1252 (1972).

Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 226–227, December 1986

BOOK REVIEW

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The Encyclopedia of Aquatic Life. Edited by K. Banister and A. Campbell. Facts On File Publications, New York. XXXIII + 349 pp. Price $35.00.

My major criticism of this book is its title, which implies a broader coverage of aquatic organisms than is delivered. This is a book about only certain groups of freshwater and marine animals. In the preface, the editors explain that amphibians are not included because they only "return to the water to breed" and pinnipeds are omitted because they "leave the sea to breed on land." Plants and bacteria also are not covered. I will have more to say about this later.

The book is intended for a general audience. It is divided into three parts. In each part, the discussions are organized around broad taxonomic groupings. The first part covers freshwater and marine fishes. The second part surveys invertebrates, excluding insects and spiders but, for some reason, including many parasitic forms. The third part of the book describes whales, dolphins and sea cows. At the start of each chapter, information on the taxonomy, geographic distributions and size ranges of each group is summarized concisely in boxes. There is a short glossary and index at the end.

Twenty-eight scientists are listed as contributors to the book. The editors have done a good job of maintaining a consistent style throughout. The text is relatively free of errors and does not overgeneralize. On the whole, I thought the parts on fishes and marine mammals were more successful. I particularly enjoyed in the first part the anecdotes, such as Julius Caesar's interest in moray eels (p. 27) or how some cyprinds become drunk by gorging themselves on fermented fruit (p. 79).

A strong point of the book is its illustrations. Most of the photographs and drawings are in color. They complement well the text. I often found myself flipping through the pages simply to look at the pictures, many of which are stunning.

Without photosynthetic production by plants, none of the animals in this book could exist. Plants are an essential part of freshwater and marine systems, and I wonder why the editors did not include them in a book claiming to be an encyclopedia of aquatic life. There is only one short paragraph on marine phytoplankton in the section on zooplankton (p. 154), and seaweeds and aquatic angiosperms are only mentioned incidentally as food and habitats for various animals. They are not even given listings in the index. I also find it inconceivable that seals are not discussed. A section on pinnipeds should accompany the chapters on other marine mammals.

Because this book does not live up to its title, I can give it only a qualified recommendation. Serious amateurs and students will find much useful information on the animal groups that are covered. The text is very readable and the illustrations outstanding.

Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 228–236, December 1986

Increased Uptake of Thymidine in the Activation of Sea Urchin Eggs: IV. Effects of the Nucleoside Transport Inhibitor, Nitrobenzylthioinosine

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ABSTRACT

Uptake of thymidine in *Strongylocentrotus purpuratus* eggs increases greater than 50-fold shortly after fertilization. This uptake is inhibitable by nitrobenzylthioinosine (NBMPR). Binding of NBMPR to surface sites on fertilized eggs is not Na^{+}-dependent. Binding to parthenogenetically activated eggs in Ca^{2+}-free sea water (OCa^{2+}-SW), however, reveals a Ca^{2+}-dependent component. Measurements of thymidine uptake in OCa^{2+}-SW also reveal a Ca^{2+}-dependent component. Along with its inhibitory effects on thymidine uptake, NBMPR exerts inhibitory effects on cleavage and early embryonic development.

Introduction

It has long been thought that the overall activation of the sea urchin egg into development starts with structural and functional changes at the cell surface. This idea follows naturally from observing the first events of fertilization and led the earliest investigators to advance the "permeability theory"[1] or to describe fertilization as a "cytolysis of the cell surface."[2] Although these descriptions lacked modern detail, they projected the direction of the numerous investigations conducted since then. It is now confirmed that there is a generalized increase in permeability and there is a massive reorganization of the egg surface after fertilization (reviewed by Giudice[3] and Epel[4]).

Reports from this laboratory [5–7] and numerous other laboratories have confirmed that sea urchin eggs exhibit a massive increase in nucleoside uptake shortly after fertilization (reviewed by Nishioka *et al.*[8]). This increase provides an exam-

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ple, among many others, of a functional change at the egg surface following fertilization (reviewed by Nishioka[9]). The physiological role of increased nucleoside uptake is not readily obvious, since fertilized sea urchin eggs are able to develop in seawater devoid of nucleosides. Nevertheless, it has long been known that sea urchin embryos readily utilize exogenously supplied nucleosides in nucleic acid synthesis.[10] The increase may be a reanimation of a cellular process that was important during oogenesis when stores of metabolic precursors need to be accumulated. Additionally, Pardee *et al.*[11], among others,[12–14] have noted that increased nucleoside uptake is observed in virtually all proliferating animal cells, suggesting that it may represent a general response of mitogenically stimulated cells.

The rate of nucleoside uptake increases greater than 50-fold shortly after fertilization[5] and is concentration dependent,[15] temperature dependent,[16] Na^+-dependent,[5] and inhibitable by 2,4-dinitrophenol.[16,17] All of the deoxyribo-ucleosides and ribonucleosides normally present in DNA and RNA compete with the DNA-specific deoxyribonucleoside, thymidine, for transport sites. The free pyrimidine and purine bases, the deoxyribose and ribose sugars, the deoxyribonucleotides, and amino acids do not compete, showing that the specificity of this uptake lies at the nucleoside level.[8] Uptake of thymidine may be turned on in unfertilized eggs by treatment with low concentrations of ammonia which bypasses the Ca^{2+}-requiring egg cortical reaction and experimentally raises the intracellular pH. However, when compared with uptake in fertilized eggs, uptake in ammonia-treated eggs is stimulated later and to a lower rate. Both of these deficiencies may be reversed by a subsequent induction of the cortical reaction by fertilization or by experimental treatments with either butyric acid or the Ca^{2+}-ionophore A23187.[5,8] These results suggest that both the Ca^{2+}-requiring cortical reaction and increased intracellular pH are involved in the turn on of nucleoside uptake in fertilized eggs.

In heretofore unrelated studies, nitrobenzylthioinosine (NBMPR) and various similar compounds have been shown to act as potent and specific inhibitors of nucleoside uptake in human erythrocytes[18,19] and various other mammalian cell-types.[20–23] In HeLa cells, for example, the transport mediated component of adenosine uptake was eliminated in the presence of 5 μM NBMPR, revealing a nonsaturable component of uptake which might represent simple diffusion.[20] HeLa cells possess sites to which NBMPR binds reversibly, but with high affinity (K_d about 0.1 nM), and NBMPR occupancy of these sites results in the inhibition of uptake of various nucleosides.[24]

The present study was undertaken to determine the effects of NBMPR on the uptake of thymidine in fertilized sea urchin eggs and to determine if NBMPR exerts any negative effects on the early development of embryos.

Materials and Methods

Experimental Sea Waters. Artificial sea water (ASW) was prepared according to the Woods Hole formula of Harvey:[25] 0.423 M NaCl; 0.009 M KCl; 0.00927 M $CaCl_2$; 0.02294 M $MgCl_2$; 0.0255 M $MgSO_4$; 0.00215 M $NaHCO_3$; pH 8.0. Na^+-free sea water ($0Na^+$-SW) was prepared according to the same formula, substituting choline chloride for NaCl and $KHCO_3$ for $NaHCO_3$. Ca^{2+}-free sea water ($0Ca^{2+}$-SW) was prepared according to the same formula, substituting NaCl for $CaCl_2$ to give a final NaCl concentration of 0.4323 M.

Procurement of Gametes. Sea urchins, *Strongylocentrotus purpuratus* were purchased from Pacific Biomarine Laboratories, Inc. (Venice, California) and maintained at 15°C in Instant Ocean aquaria containing Instant Ocean synthetic sea water. Shedding of gametes was induced by intracoelomic injection of 0.55 M KCl. Semen was shed directly into Syracuse dishes and maintained ice cold and undiluted until use. Eggs were shed directly into ASW, dejellied by agitation, and allowed to settle through three changes of ASW at 15°C.

Fertilization and Parthenogenetic Treatment. Fertilization was achieved by adding 0.01 vol of stock sperm suspension (1 drop undiluted semen in 5 ml ASW) to 1% (v/v) egg suspensions in ASW. For parthenogenesis, a 5.0 mM stock solution of Ca^{2+}-ionophore A23187 (Calbiochem-Behring) was prepared in dimethyl sulfoxide and added to 1% egg suspensions to a final concentration of 20 μM. These procedures resulted in greater than 98% fertilization and parthenogenetic activation, as determined microscopically by the appearance of elevated fertilization coats.

Measurements of Uptake and Binding. Uptake of [^{3}H-methyl]-thymidine (ICN, 60 Ci/mmole) and binding of [^{3}H]-NBMPR (Moravek Biochemicals, 35-37 Ci/mmole) were measured in this study. Crystalline NBMPR (Aldrich) was used in inhibition experiments. For measurements of [^{3}H]-thymidine uptake, standard 1% (v/v) egg suspensions were prepared in the various experimental sea waters containing 1.0 μCi/ml [^{3}H]-thymidine and cultured at 15°C with swirling every 5 min. At timed intervals after fertilization or parthenogenetic activation, 5.0 ml samples were removed from the cultures, placed in 15 ml conical centrifuge tubes, and centrifuged at 300 × g for 1 min. After two 5 ml washings with the appropriate ice cold sea water, the egg pellets were suspended in 0.5 ml NCS tissue solubilizer (Amersham) : H_2O (9 : 1) and incubated at 50°C for 2 hr. The dissolved samples were transferred to scintillation vials with two 5 ml washings of scintillation fluid (5.0 g PPO, 0.1 g POPOP per liter toluene). Radioactivity in each sample was measured with a Beckman LS 7500 liquid scintillation counter. For measurements of [^{3}H]NBMPR binding, 1% egg suspensions containing 20 nM [^{3}H]-NBMPR were cultured at 15°C and stirred continuously at 60 rpm with motor-driven teflon paddles. At timed intervals after exposure to [^{3}H]-NBMPR, 2.5 ml samples were removed from the cultures and processed as described for uptake of [^{3}H]-thymidine, except that the sample pellets received only one wash with the appropriate ice-cold sea water.

Na^+-Free and Ca^{2+}-Free Experiments. In experiments involving Na^+-free or Ca^{2+}-free conditions, the eggs were washed three times with at least 50 vol $0Na^+$-SW or $0Ca^{2+}$-SW by centrifugation and aspiration of supernates. In experiments comparing binding under Na^+-free and Na^+-containing conditions, two cultures were set up under Na^+-free conditions and NaCl was added to one of the cultures to a final concentration of 50 mM. In experiments comparing binding or uptake under Ca^{2+}-free and Ca^{2+}-containing conditions, two cultures were set up under Ca^{2+}-free conditions and $CaCl_2$ was added to one of the cultures to a final concentration of 10 mM.

Results

Uptake of [^{3}H]-Thymidine

Figure 1 shows the cumulative uptake of [^{3}H]-thymidine in unfertilized and fertilized sea urchin eggs. Unfertilized eggs show a low, constant rate of uptake, while fertilized eggs exhibit a sharp increase 10 min after insemination which begins to plateau at 80–90 min. The plateau reflects the exhaustion of thymidine from the medium and demonstrates the extreme efficiency of this transport system. The difference in the amounts of uptake through the first 90 min between unfertilized and fertilized eggs represents a greater than 50-fold increase in the rate of thymidine uptake following fertilization. These results further confirm earlier reports from this laboratory.[5–8]

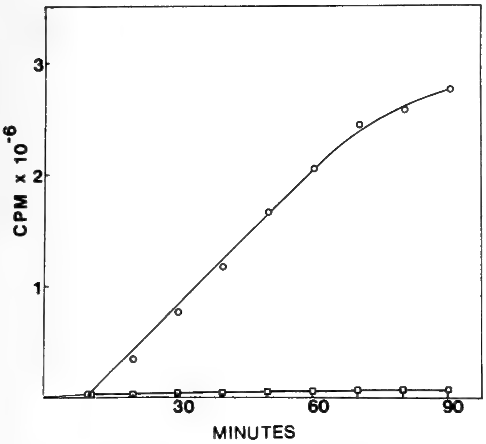

Fig. 1. Cumulative uptake of [^{3}H]-thymidine (1.0 μCi/ml, 60 Ci/mmole) in unfertilized [□] and fertilized [○] sea urchin eggs. Insemination is at time 0.

Effects of NBMPR on [^{3}H]-Thymidine Uptake

To determine the effects of NBMPR on thymidine uptake in fertilized eggs, the cumulative uptake of [^{3}H]-thymidine was measured at 60 min post-insemination in the presence of increasing concentrations of NBMPR. Figure 2 shows the reductions in uptake, and corresponding % inhibitions, as the concentration of NBMPR is raised from 0 to 400 μM. Uptake is reduced rapidly to 60% inhibition between 0 and 100 μM and continues to fall, although much less rapidly, to 80% inhibition between 100 and 400 μM.

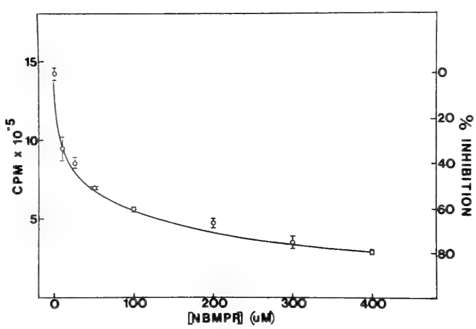

Fig. 2. Inhibition of [^{3}H]-thymidine uptake by nitrobenzylthioinosine (NBMPR). Cumulative uptake in fertilized sea urchin eggs exposed to increasing concentrations of NBMPR was measured at 60 min post-insemination. Error bars indicate standard deviations from the means for three samples measured at each NBMPR concentration.

Binding of [^{3}H]-NBMPR in 0Na$^+$-SW

Since a strict requirement for external Na$^+$ has been reported for thymidine transport[5] and since our results indicate that NBMPR is an effective inhibitor of this transport, the binding of [^{3}H]-NBMPR to fertilized eggs was compared under Na$^+$-containing and Na$^+$-free conditions. For this comparison, eggs were fertilized in ASW, washed three times with 0Na$^+$-SW, divided into two equal suspensions, and cultured at 15°C with constant stirring. At time 0, [^{3}H]-NBMPR (*q.s.* 20 nM) was added to one of the cultures and [^{3}H]-NBMPR (*q.s.* 20 nM) + NaCl (*q.s.* 50 mM) were added to the second culture. Figure 3 shows that there is no significant difference in NBMPR binding through a 45 min comparison. Apparently, binding of NBMPR to surface sites on fertilized sea urchin eggs is not Na$^+$-dependent.

Binding of [^{3}H]-NBMPR in 0Ca^{2+}-SW

When a similar comparison was made between Ca^{2+}-containing and Ca^{2+}-free

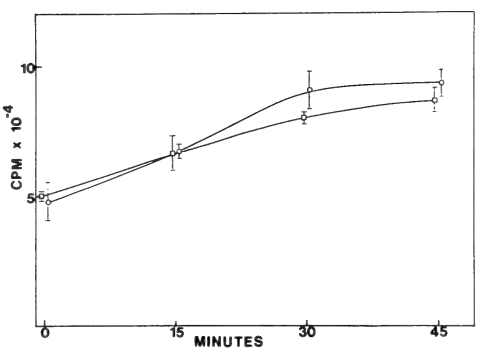

Fig. 3. [^{3}H]-NBMPR binding to fertilized sea urchin eggs suspended in 0Na$^+$-SW [□] and 0Na$^+$-SW containing 50 mM NaCl [○]. Error bars indicate standard deviations from the means for three samples measured at each timepoint.

conditions, a significant reduction in the amount of [^{3}H]-NBMPR binding was detected in $0Ca^{2+}$-SW. For this comparison, unfertilized eggs were washed three times in $0Ca^{2+}$-SW, divided into two equal suspensions and cultured at 15°C with constant stirring. At time 0, [^{3}H]-NBMPR (*q.s.* 20 nM) + ionophore A23187 (*q.s.* 20 μM) were added to one of the cultures and [^{3}H]-NBMPR (*q.s.* 20 nM) + ionophore A23187 (*q.s.* 20 μM) + $CaCl_2$ (*q.s.* 10 mM) were added to the second culture. Elevation of fertilization coats was greater than 98% in both cultures. Figure 4 shows a 50% reduction in [^{3}H]-NBMPR binding under Ca^{2+}-free conditions through a 45 min comparison. These results reveal for the first time the existence of a Ca^{2+}-dependent component of NBMPR binding.

Parthenogenetic activation by A23187 was chosen for these experiments because the sperm acrosome reaction and fertilization are inhibited in $0Ca^{2+}$-SW. Additionally, fertilization coats fail to harden in $0Ca^{2+}$-SW, making excessive clumping during transfer of fertilized eggs to $0Ca^{2+}$-SW an operational difficulty.

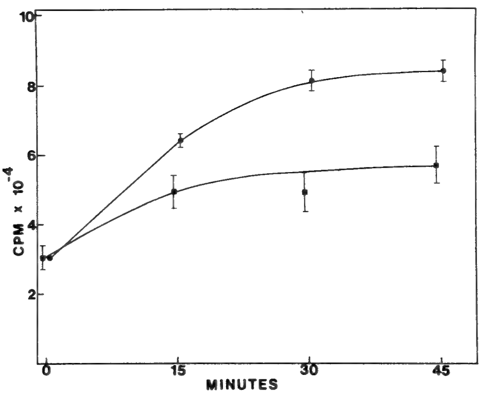

Fig. 4. [^{3}H]-NBMPR binding to ionophore A23187-activated sea urchin eggs suspended in $0Ca^{2+}$-SW [■] and $0Ca^{2+}$-SW containing 10 mM $CaCl_2$ [●]. Error bars indicate standard deviations from the means for three samples measured at each timepoint.

[^{3}H]-*Thymidine Uptake in* $0Ca^{2+}$-*SW*

Since the binding of NBMPR was shown to be Ca^{2+}-dependent, the determination of whether thymidine uptake is also Ca^{2+}-dependent was made. Unfertilized eggs were washed three times in $0Ca^{2+}$-SW and divided into four equal suspensions containing 1.0 μCi/ml [^{3}H]-thymidine and cultured at 15°C. At time 0, ionophore A23187 (*q.s.* 20 μM) was added to one of the cultures and ionophore A23187 (*q.s.* 20 μM) + $CaCl_2$ (*q.s.* 10 mM) were added to a second culture. The third and fourth cultures were used as unactivated controls with and without Ca^{2+}. Figure 5 shows that the stimulation of thymidine uptake in A23187-treated eggs under Ca^{2+}-containing conditions is similar to the stimulation observed in fertilized eggs suspended in ASW (compare with Fig. 1). Uptake in $0Ca^{2+}$-SW, however, is nearly 20% reduced through the 45 min course of the experiment. These results reveal a Ca^{2+}-dependent compo-

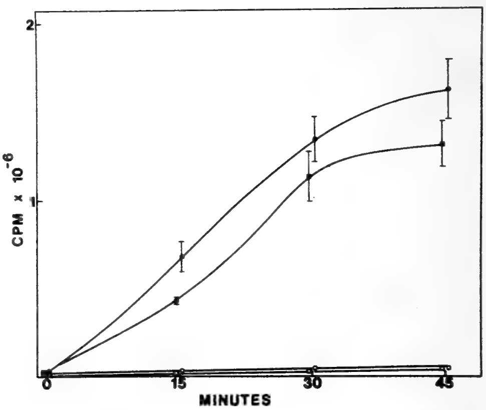

Fig. 5. Cumulative uptake of [^{3}H]-thymidine in sea urchin eggs: unfertilized eggs suspended in $0Ca^{2+}$-SW [□]; unfertilized eggs suspended in $0Ca^{2+}$-SW containing 10 mM $CaCl_2$ [○]; ionophore A23187-activated eggs suspended in $0Ca^{2+}$-SW [■]; and ionophore A23187-activated eggs suspended in $0Ca^{2+}$-SW containing 10 mM $CaCl_2$ [●]. A23187 activation is at time 0. Error bars indicate standard deviations from the means for three samples measured at each timepoint.

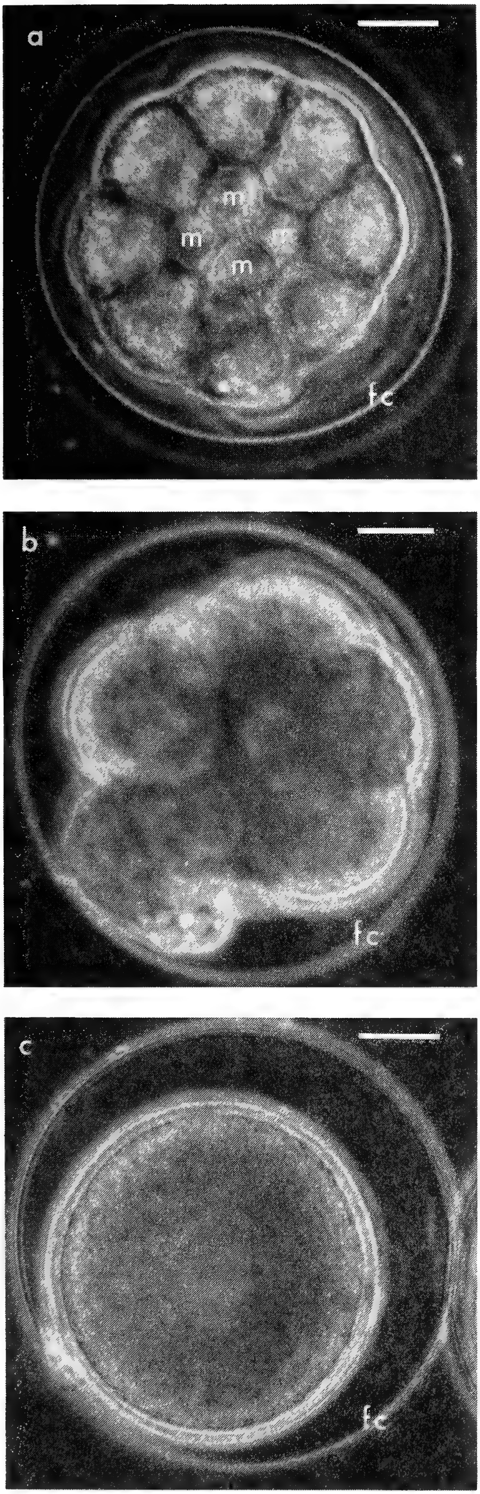

Fig. 6. Phase-Contrast micrographs of fertilized sea urchin eggs 6 hr post-insemination in ASW [a], ASW containing 50 μM NBMPR [b], and ASW containing 400 μM NBMPR [c]. fc = fertilization coat, m = micromeres, bars = 20 μm.

nent of thymidine uptake in activated eggs.

Effects of NBMPR on Early Embryonic Development

Figure 6a shows a sea urchin embryo cultured in ASW 6 hr after fertilization. Development to the sixteen-cell stage and appearance of a quartet of micromeres has proceeded normally. Figures 6b and 6c show embryos cultured for 6 hr in ASW containing 50 μM and 400 μM NBMPR, respectively. In the presence of 50 μM NBMPR, cell division proceeds but the normal cleavage planes are disrupted and a definitive quartet of micromeres fails to appear at the scheduled time. In 400 μM NBMPR, cleavage is totally inhibited. These results show that along with its inhibitory effects on thymidine uptake, NBMPR exerts inhibitory effects on cleavage and early embryonic development.

Discussion

In the present study, a drug known to inhibit nucleoside uptake in many types of vertebrate cells has been tested on fertilized sea urchin eggs. Nitrobenzylthioinosine (NBMPR) has been shown to bind to high affinity binding sites on the plasma membranes of human erythrocytes.[26,27] These sites are present at 1.0–1.5 × 10^4/cell, bind NBMPR with an apparent K_d of 1 nM, and, since inhibition of uridine uptake is proportional to the number of sites occupied by NBMPR, are presumed to play an important role in the nucleoside uptake mechanism.[27] Although nucleosides can compete with NBMPR for binding sites, Cass and Paterson have provided a cogent study which suggests that NBMPR binding sites are different from nucleoside uptake sites.[28]

Human erythrocytes are highly differentiated, anucleate cells and, as such, have lost their abilities to replicate DNA and synthesize RNA. The ability to metabolize transported nucleosides to the mono-, di-, and triphosphorylated nucleotides is also lost. On the other hand, all nucleated, dividing cells, including human cancer (HeLa) cells[29] and fertilized sea urchin eggs,[6–8,30] rapidly metabolize transported nucleosides. In HeLa cells, it has been shown that NBMPR is a potent inhibitor of nucleoside uptake,[24,29] but that thymidine and uridine kinase activities in cell extracts are unaffected by NBMPR concentrations well in excess of those which block nucleoside transport.[29] Apparently, NBMPR does not inhibit nucleoside transport in HeLa cells by inhibiting a metabolic coupling of transport with nucleoside phosphorylation. Rather, transport is blocked specifically.

Our results show that NBMPR also inhibits nucleoside uptake in fertilized sea urchin eggs, but to a lesser extent than that shown in other vertebrate cells. For example, while 5 μM NBMPR is sufficient to completely inhibit nucleoside uptake in HeLa cells, 400 μM NBMPR is required to achieve an 80% inhibition of thymidine uptake in fertilized sea urchin eggs. Additionally, the inhibition curve shown in Figure 2 indicates that a significant portion (ca., 20%) of thymidine uptake remains insensitive to NBMPR. This type of inhibition is apparently not limited to the early cleavage stages of development reported here, because virtually identical inhibition curves have been generated for 48 hr (late gastrula) embryos (Eagan and Nishioka, unpublished results).

Our measurements indicate that [^{3}H]-NBMPR binds to the fertilized egg surface, but that this binding is not Na^+-dependent. Since thymidine uptake has been shown to be very strictly Na^+-dependent, our results can be interpreted as further evidence in support of the idea that NBMPR binding sites are different from nucleoside uptake sites. Both [^{3}H]-NBMPR binding and [^{3}H]-thymidine uptake, on the other hand, are shown to be partially Ca^{2+}-dependent in parthenogenetically activated eggs. Binding is reduced 50% and uptake is reduced 20% in $0Ca^{2+}$-SW. This difference can also be interpreted as evidence for separate NBMPR binding sites and nucleoside uptake sites. More importantly, Ca^{2+} is known to be involved in many receptor-mediated cellular processes and our results indicate that both NBMPR binding and thymidine uptake in activated sea urchin eggs may now be added to this list.

The most equivocal aspects of this study are (1) the extremely high concentrations of NBMPR required to inhibit thymidine uptake and (2) the adverse effects it exerts on early development. The first aspect questions the specificity of NBMPR in inhibiting nucleoside uptake. At the high concentrations used, does NBMPR inhibit all uptake? We have measured the effects of 100 μM NBMPR on the uptake of the amino acids leucine, glycine, and lysine and have observed 20%, 30%, and 35% inhibitions, respectively (unpublished results), so there is in fact some nonspecific inhibition of uptake, but not enough to conclude that NBMPR is a completely nonspecific inhibitor. The second aspect questions whether NBMPR inhibition of thymidine uptake is a cause or an effect of the inhibition of cleavage. What is needed to settle this question are determinations of the effects of NBMPR on other post-fertilization metabolic processes. One such process for which the necessary techniques have just become available and which should also provide valuable information about the mechanism of nucleoside uptake, is the phosphorylation of transported nucleosides.[30] It could be that in fertilized sea urchin eggs, unlike HeLa cells, nucleoside uptake is dependent on metabolic coupling with phosphorylation. Experiments are planned to determine the effects of NBMPR on the *in vivo* phosphorylation of transported nucleosides and the *in vitro* activities of the nucleoside kinases in sea urchin egg extracts.

Acknowledgments

This work was supported by grants from the National Institutes of Health (No. HD-19054) and the National Science Foundation (No. DMB 85-1545) to D. N.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 237–243, December 1986

SURVIVAL OF *MORONE SAXATILIS* IN LOW pH OLIGOHALINE WATERS

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ABSTRACT

The hypothesis that declines in striped bass (*Morone saxatilis*) stocks are related to acid deposition in freshwater areas of the Chesapeake Bay estuary has become widespread. Attention has focused above the freshwater/saltwater interface due to the belief that low salinity would buffer waters from pH fluctuations.

Continuous water quality monitoring of Seneca Creek waters in the Upper Chesapeake Bay revealed sustained low pH during 1985, a dry year. Low pH levels were recorded despite increasing salinity. In April, salinities of ≤3 ppt were found with pH >7, but by May pH was <6 while salinities increased to 4 ppt. Low pH (<6) persisted until late August despite salinity increasing to 6 ppt. Water quality surveys of surrounding embayments revealed isolated pockets of low pH (<6) in Seneca Creek, Middle River and Gunpowder River. These findings demonstrate that acidic conditions are possible at low salinities and may be a common occurrence in poorly buffered oligohaline estuaries.

Low pH did not affect the survival of striped bass cultured in the Crane Aquaculture Facility during 1985. No difference was seen in survival between larvae held in buffered (pH ≥ 6.2) or ambient (pH as low as 5.3) water. Larvae were exposed to pH <6 at an age of 19 days with no apparent increase in mortality.

Eight facilities, from five states, contributed striped bass to the Chesapeake Bay Striped Bass Binary Coded Wire Tagging Project; a cooperative program of the U.S.F.W.S. and Maryland Department of Natural Resources. The Crane Aquaculture Facility contributed 21.8% of the numbers and 49.8% of the biomass, demonstrating successful production during 1985. This indicates acid deposition alone is not the major factor in striped bass declines in oligohaline areas of the Chesapeake Bay.

Introduction

In recent years the concern over the degradation of biological communities in estuaries via acid deposition has received attention in both scientific and popular literature. Attention has focused on possible pH shifts occurring near the freshwater/saltwater interface. Investigators appear to have assumed the buffering capacity of oligohaline water would not permit sustained low pH and thus few pH studies have been conducted below the

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interface. Data from organically rich blackwater rivers of the Southeastern Coastal Plain suggest this assumption is not valid for all estuaries[1].

The toxic effects of acid deposition in estuaries are thought to be caused by low pH pulses. These pulses are hypothesized to have been uncommon and organisms are thus susceptible to these events. Low pH has been suggested as one possible cause for declines of striped bass (*Morone saxatilis*) stocks in the Chesapeake Bay. Larval and juvenile fish are particularly susceptible to the pulses[2,3]. Reports in scientific[3] and popular[4] literature suggested toxic effects of acidification and aluminum on striped bass and other estuarine organisms. Most studies of pH effects on striped bass have been conducted in freshwater[2,5,6] since most culture facilities are situated in freshwater environs. It has been reported that larval striped bass survival increases with low salinity[7,8]. However, studies have not been conducted to determine effects of increased salinity on the toxicity of low pH.

The Crane Aquaculture Facility uses ambient oligohaline waters to culture striped bass. During 1985 sustained low pH occurred in the nearshore waters surrounding the Crane Facility. The objective of this publication is to describe this occurrence and its impact on striped bass cultured at the facility during 1985.

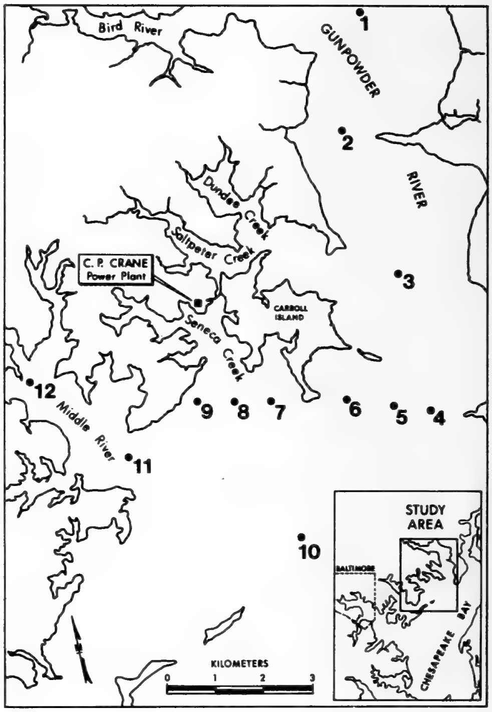

Fig. 1. Location of the Crane Aquaculture Facility at the Crane Power Plant on Seneca Creek and the stations sampled on water quality surveys.

Methods

The Crane Aquaculture Facility is located on Seneca Creek in the Upper Chesapeake Bay (Fig. 1). This facility has been operating since the spring of 1983 and utilizes a once-through system to deliver a minimum of 1250 gpm of either ambient water from Seneca Creek or warmed discharge water from a power plant for intensive culture of striped bass. Intake water is continuously monitored for temperature, conductivity, pH and dissolved oxygen. During 1985, ambient water was used for the period covered by this report after discharge canal pumps were turned off on 29 April.

Continuous water quality monitoring was conducted using Rexnord Model 3750/51 pH transmitters with Model 375 sensors, Leeds and Northrup Model 7073-17 Industrial conductivity monitors and Rexnord Model 3060 dissolved oxygen meters. Daily pH, dissolved oxygen, temperature and salinity samples were also taken. Water quality surveys were conducted on nearby embayments of the Chesapeake Bay after low pH was observed. The daily and survey water quality readings were taken using glass or plastic sampling devices, a YSI Model 51B Oxygen meter, a A0 hand refractometer, and a Fisher Model 800 Accumet pH meter.

Selected holding tanks for larvae were buffered to maintain pH levels above ambient waters. Reservoirs of bicarbonate solution were used to maintain a controlled drip of buffer, via pumps, to mix with incoming ambient waters in the holding tanks. Other holding tanks received unbuffered ambient waters for comparison of larval survival.

Results

The pH of ambient waters flowing through Crane Aquaculture Facility decreased while salinities increased (Fig. 2). From April to May pH levels were ≥7 while salinities were ≤3 ppt. By the end of May the pH had dropped below 6 while salinity increased to 4 ppt. The pH remained consistently below 6 while salinity increased to 6 ppt by late August, after which pH levels started to rise.

To document the occurrence of low pH in the embayments near the Crane Facility water quality surveys were conducted at selected stations (Fig. 1). The first survey, 14 August, found pH levels below 6

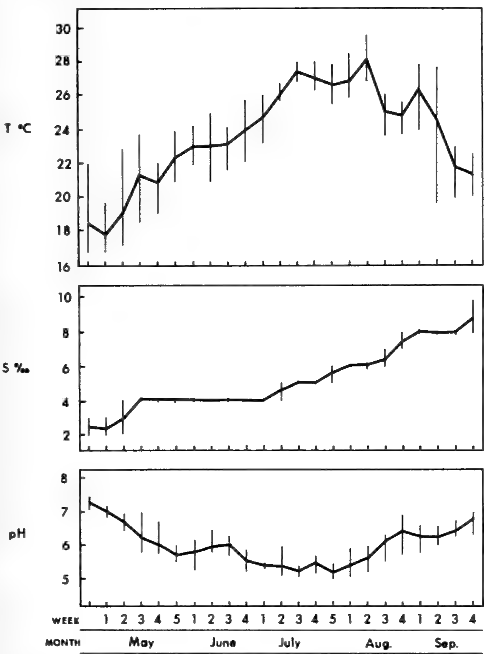

Fig. 2. Weekly averages and ranges for pH, salinity and temperature of intake waters of the Crane Aquaculture Facility for April–September 1985.

Table 1.—Results of water quality samples taken in a survey on 14 August 1985. Station locations are shown on Fig. 1.

Station	Depth (ft)	pH	Temp. (°C)	Salinity (%)
3	0	5.9	29.9	6.0
	2	5.9	28.3	6.0
4	0	6.8	29.4	6.0
	2	6.8	28.1	6.0
5	0	6.7	29.2	6.0
	2	6.7	28.0	6.0
6	0	6.8	29.1	6.0
	2	6.7	28.8	6.0
7	0	6.0	29.1	6.0
	2	5.9	28.0	6.0
8	0	5.9	29.1	6.0
	2	5.6	28.9	6.0
9	0	5.9	29.0	6.0
	2	5.9	28.8	6.0
10	0	7.8	28.9	7.0
	2	7.8	28.0	7.0
11	0	5.8	29.0	6.0
	2	5.7	28.8	6.0

Table 2.—Results of water quality samples taken in a survey on 19 August 1985. Station locations are shown on Fig. 1.

Station	Depth (ft)	pH	Temp. (°C)	Salinity (%)
1	0	6.8	27.1	4.5
	6	6.8	25.0	4.5
2	0	6.8	26.7	5.0
	6	5.9	25.0	5.0
3	0	5.6	26.0	6.0
	6	6.5	25.0	6.0
4	0	7.4	26.0	7.0
	6	7.4	24.8	7.0
5	0	7.2	25.7	7.0
	6	7.3	25.3	7.0
6	0	6.7	25.7	7.0
	6	7.0	25.2	7.5
7	0	6.2	25.1	6.0
	6	6.5	24.7	6.5
8	0	6.6	25.0	6.5
	6	6.7	25.0	6.5
9	0	6.5	25.3	7.0
	6	6.5	24.9	7.0
10	0	7.3	26.0	7.0
	6	7.3	25.8	8.0
11	0	5.3	25.3	6.0
	6	5.5	25.1	7.0

on the Gunpowder River, Seneca Creek and Middle River while a pH of 7.8 was found in Chesapeake Bay waters (Table 1). On 19 August pH levels below 6 were found in the Gunpowder River and Middle River while bay waters had a pH of 7.3 (Table 2). On 16 September only the Gunpowder River had a pH below 6 (Table 3). A 16 October survey found pH patterns similar to the 16 September survey (Table 4). Stations 2 and 3 in Gunpowder River and 11 in Middle River were where low pH was most commonly found.

Three separate groups of larval striped bass were raised in the Crane Aquaculture Facility during 1985. Two groups arrived as one day old larvae on 19 April and 29 April. The last group arrived as 5 day old larvae on 15 May. Some larvae were held in tanks buffered with sodium bicarbonate to a pH above 6.2 while ambient water pH dropped to 5.3. Larvae of groups 1 and 2 were moved from the buffered tanks before ambient pH fell below 6.1 (buffered tanks ≥6.5). Group 3 larvae were the eldest held in buffered tanks (buffered tanks ≥6.2, ambient tanks ≥5.3), until the age of 25 days. Approximately 40% of the striped bass of groups 1 and 2 were held in buffered tanks until 13 May. Approximately 67% of group 3 were held in buffered tanks until 4 June. No apparent difference in survival of larvae was seen between tanks receiving buffered or

Table 3.—Results of water quality samples taken in a survey on 16 September 1985. Station locations are shown on Fig. 1.

Station	Depth	pH	Temp. (°C)	Salinity (%)
1	Surf.	6.4	20.0	5.0
	Bott.	6.3	19.0	6.0
2	Surf.	6.5	20.3	6.0
	Bott.	5.3	19.0	7.0
3	Surf.	6.3	20.5	7.0
	Bott.	6.2	19.3	7.5
4	Surf.	7.5	21.5	8.0
	Bott.	7.3	19.5	8.0
5	Surf.	7.0	21.0	8.0
	Bott.	7.0	19.7	8.0
6	Surf.	6.4	20.0	8.0
	Bott.	6.9	19.5	8.0
7	Surf.	6.5	20.0	8.5
	Bott.	6.5	19.1	9.0
8	Surf.	7.0	19.8	8.0
	Bott.	6.7	19.3	9.0
9	Surf.	6.9	20.0	8.2
	Bott.	6.9	19.5	9.0
10	Surf.	7.5	22.0	8.0
	Bott.	7.3	21.0	10.0
11	Surf.	6.1	20.4	9.0
	Bott.	6.2	19.8	9.0
12	Surf.	7.6	21.0	8.5
	Bott.	6.8	20.0	8.5

Table 4.—Results of water quality samples taken in a survey on 16 October 1985. Station locations are shown on Fig. 1.

Station	Depth	pH	Temp. (°C)	Salinity (%)
1	Surf.	7.5	18.3	4.0
	Bott.	6.5	18.3	5.0
2	Surf.	6.1	18.0	6.0
	Bott.	5.8	18.0	6.0
3	Surf.	7.0	18.0	7.0
	Bott.	7.1	18.3	7.0
4	Surf.	7.4	19.0	7.5
	Bott.	7.4	18.8	8.0
5	Surf.	7.1	18.7	7.5
	Bott.	7.2	18.7	7.5
6	Surf.	7.1	19.0	8.0
	Bott.	7.1	18.7	7.5
7	Surf.	7.3	19.3	8.0
	Bott.	7.1	19.3	8.5
8	Surf.	7.2	19.0	8.0
	Bott.	7.3	19.0	8.0
9	Surf.	7.2	19.0	8.0
	Bott.	7.3	18.7	9.0
10	Surf.	7.5	19.0	8.0
	Bott.	7.5	19.0	9.0
11	Surf.	6.1	19.0	8.5
	Bott.	6.4	19.0	8.5
12	Surf.	6.7	18.7	8.0
	Bott.	6.5	18.7	8.0

Table 5.—Striped bass age at initial exposures to low pH levels.

pH	Age (Days) at Initial Exposure Group I	Group II	Group III
>7.0	1	1	8
7.0–6.5	12	3	5
6.5–6.0	24	15	26
6.0–5.5	28	19	28
5.5–5.0	46	37	45
<5.0	102	93	78

Table 6.—Contributions to the Binary Coded Wire Tagging Project during 1985.

Facility	Number of Fish	Percent	Weight of Fish (lb)	Percent
Manning (MD)	4723	2.5	189*	1.3
Crane Aqua. (MD)	40672	21.8	6977	49.8
Horn Point (MD)	6405	3.4	237**	1.7
Harrison Lake (VA)	61840	33.1	3092*,†	22.1
McKinney Lake (NC)	7404	4.0	370†	2.6
Edenton (NC)	56851	30.4	2842†	20.3
Orangeburg (SC)	3939	2.1	197†	1.4
Frankfort (KY)	5092	2.7	113*	0.8
Total	186926	100.0	14017	100.0

*Estimates, personal communication, J. Stringer, MDDNR
**Estimates, personal communication, R. Harrell, Univ. MD.
†Estimates, personal communication, C. Wooley, USFWS

ambient waters. Striped bass were exposed to pH levels below 6.5 at ages of 15, 24 and 26 days, below 6 at ages of 19 (group 1) and 28 days (groups 2 and 3), and below 5.5 at ages of 37, 45 and 46 days (Table 5). Survival during 1985 was the best observed for the history of the facility.

The U.S. and Wildlife Service and the Maryland Department of Natural Resources established a binary coded wire tagging project for striped bass stocked into the Chesapeake Bay. During 1985 eight facilities located in Maryland, Virginia, North Carolina, South Carolina and Kentucky produced 186,926 fish for the tagging Program (Table 6). The Crane Aquaculture Facility contributed 21.8% of the number and 49.8% of the biomass of striped bass tagged (Table 6), indicative of good production during 1985.

Discussion

Occurrence of low pH

The belief that low salinity concentrations sufficiently buffered estuarine waters to prevent sustained pH shifts has been proven unjustified by this study. It has been stated that a salinity of 2-10 ppt would buffer sufficiently to negate pH fluctuations[5]. The ambient waters from Seneca Creek were found to drop in pH from above 7 to below 5.5 from April to June 1985 (Fig. 2). The pH level remained consistently below 6 from the last week in May until the third week in August.

As the pH dropped the salinity increased from 2 ppt (April) to 5 ppt (May-Fig. 2) and some pH sample levels remained below 6 in September even though salinity increased to 8 ppt. These data show that low pH levels occur in oligohaline waters and can exist for extended time periods.

The cause of the low pH during 1985 is not known. Four possible mechanisms can be proposed: 1) freshwater inflow from the Susquehanna River; 2) acid deposition from rain; 3) decaying material causing increased hydrogen sulfide; and 4) ground water infiltration.

The discharge of the Susquehanna River at the Conowingo Dam ranged from approximately 200 to 940 m^3/min from April to August 1985, a dry year, as compared to 500 to 2760 m^3/min for the same period of 1984, a wet year. This inverse relationship between river flow and pH eliminated major drainage inputs as possible causes of the observed decline.

Local acid rain can be eliminated by noting the results of the water quality surveys conducted during 1985 (Fig. 1 and Tables 1-4). Isolated pockets of embayments gave pH levels below 6. Stations in the bay and often upstream of the isolated pockets gave much higher pH levels (≥6.5) indicating a local, isolated source for the low pH waters. The relative constancy of the low pH over long periods also suggests other mechanisms for its development and maintenance.

Decomposition of organic material from local aquatic weed beds and nutrient enriched waters could lead to a pH decline by causing anaerobic conditions and the release of hydrogen sulfide. We did not observe low dissolved oxygen in the facility, but did not measure this parameter on our surveys. It seems unlikely this mechanism can explain the low pH.

Groundwater in the region can be acidic[9,10,11]. It is possible ground water is entering at this area, but we did not observe any decline in salinity of the bottom waters near areas of low pH. No definitive answer is available on the cause of the pH decline. Studies are continuing to gain information on possible sources of the acidic conditions.

The low pH during 1985 was not an isolated occurrence for the area. A study during 1980, another dry year, reported low pH in September when pH levels below 6 were found at salinities of 6-7 ppt in the same areas as the present study[12]. The findings of these studies raises questions about the source and occurrence of low pH waters in oligohaline reaches of Chesapeake Bay. Low pH may be more common than previously thought in poorly buffered estuarine waters.

Striped bass survival

Despite low pH in the source waters of the Crane Aquaculture Facility, 1985 was one of the best years for survival of striped bass larvae cultured in the facility. The levels of pH described as toxic in the literature indicated larvae should not have survived[2,3,6,7]. Studies have established that survival of striped bass larvae is enhanced by low salinity[3,7,8,13]. Low salinity may reduce toxic effects associated with low pH levels.

Larval fish cultured to juvenile stages in the Crane facility during 1985 arrived in three groups. Two groups arrived as one day old post-hatch while the last group arrived as five day old post-hatch. Approximately 40% of groups 1 and 2 and approximately 67% of group 3 were held in buffered waters. Larvae survived pH below 6 from ages of 19 (group 1) and 28 days (groups 2 and 3). This is below the tolerance range cited in the literature[6,14]. The final group of fish were held in water buffered to pH levels above 6.2 while ambient intake waters were as low as 5.3. No difference was observed between the larvae cultured in buffered or ambient waters indicating little, if any, toxic effects due to low pH.

The fact that 1985 was a good year for producing striped bass at the Crane Aquaculture Facility is supported by the percent contribution the facility made to stocking efforts through the Binary Coded Wire Tagging Project (Table 6). Most of the facilities involved contributed the majority or all of their production to the tagging project. The Crane Facility's contribution was 40,672 fish for 21.8% of the numbers tagged and 49.8% of the biomass (Table 6). The large biomass (highest of all facilities) in comparison to the number (third largest) of fish indicates the excellent condition of the fish produced at the Crane Facility under low pH conditions in oligohaline waters.

The pH toxicity studies for striped bass have been conducted in freshwater because most spawning occurs in freshwater reaches of rivers and most hatcheries utilize freshwater sources. Doroshev[2] found sudden pH shifts of 0.8 to 1.0 units were toxic to striped bass larvae in freshwater. Setzler et al.[14] listed the pH tolerance range of larval striped bass (<20 mm) as 6-9 and a tolerance range for young fish of 6-10. Hall et al.[3] speculated that aluminum concentrations at a pH of about 6.3 caused mortalities for larval striped bass in the Nanticoke River, Maryland. However, the experimental controls of this study were maintained at salinities of 1-3 ppt while the treatments were at 0-0.9 ppt. Since low salinities enhance survival the results of Hall et al. may be partially explained by salinity differences rather than toxic effects of pH and aluminum. Palawski et al.[13] found low salinity (1 and 5 ppt) decreased the toxic effects of several organic or inorganic contaminants.

It is possible low salinty levels would alleviate the effects of lowered pH (via acid deposition or other sources) near striped bass spawning areas. Striped bass spawn mainly in the first 25 miles of freshwater with good flows[7]. Eggs and larvae drift with currents (until larvae are about 5 days old) and many reach oligohaline areas of the estuary. The saltier areas may counteract the impacts of acid deposition that has been hypothesized as the cause of striped bass stock decreases in scientific[3] and popular[4] literature. If oligohaline waters offer refuge for striped bass from the toxic effects of acid deposition, it is unlikely that the drastic declines in stocks could be caused by acid deposition.

More research must be conducted on the interaction of acid inputs in oligohaline waters, especially poorly buffered estuaries, and related toxic effects. The belief that small salinity concentrations will buffer waters from pH fluctuations is no longer viable. However, the low salinity waters may not exhibit the toxic effects for low pH and contaminants seen in freshwaters. Research needs to be conducted on the interaction of salinity with toxicants to answer questions on possible impacts in oligohaline waters.

Acknowledgments

This study was funded by Baltimore Gas and Electric Company through its Crane Aquaculture Facility. We would like to acknowledge the technical assistance of Mr. Steve Farkas and Ms. Margie McCarthy with this project.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 244–249, December 1986

Euplotes iliffei n.sp.: A new species of *Euplotes* (Ciliophora, Hypotrichida) from the marine caves of Bermuda.

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ABSTRACT

Euplotes iliffei n.sp., a new anchialine species of *Euplotes* from the marine caves of Bermuda is described. *E. iliffei* has a dorsal interkinetal argentophilic reticulum of the multiple to complex type with a tendency toward 4 interkinetal polygonal areas. Like other members of the group of *Euplotes* that have a frontoventral cirri in pattern I the VI/2 cirrus is missing. *E. iliffei* also has a very pronounced notch in the upper border of the dorsal surface.

Introduction

The limestone platform that makes up the Bermuda Islands is composed of Pleistocene and recent, marine and eolian limestones which overlay a mid-ocean volcanic sea mount. Most of Bermuda's caves were formed when sea level lowered during periods of glaciation as a result of dissolution by slightly acidic percolating ground waters. The caves were subsequently flooded by marine waters when sea level rose during postglacial periods (1,2). Extensive horizontal cave passages, some being more than 2.0 km in length, have been explored and mapped utilizing sophisticated cave diving techniques (3,4).

Recent studies on marine animals inhabiting these subterranean anchialine habitats has revealed the presence of diverse endemic macro-invertebrate faunas (5,6,7). However, during these earlier cited comprehensive cave faunal surveys, samples containing possible cave protozoa were not collected. Newer studies are currently examining these same caves for protozoa, and a rich and diverse anchialine ciliated protozoa fauna has been established (8). Included among the new ciliated protozoa are several species of *Euplotes*, one of which is described here.

In the literature over 80 species and varieties of *Euplotes* have been described in the last 200 years, many of which are now considered junior synonyms as reviewed by Hill, 1980 (9). Curds (10) in his 1975 guide to the genus listed 51 different species of *Euplotes*. In the last few years several new species have been described. Jones and Owen (11) described *E. nana* and Ten Hagen (12) characterized *E. palustris*. *E. terricola* originally described by Penard (13) is no longer considered a member of the genus *Euplotes* because of the spatial arrangement of the frontoventral and transverse cirri and the presence of many left marginal cirri. Thus, we now consider there to be 52 valid species in the genus *Euplotes*. This paper describes the first anchialine species of *Euplotes* (*Euplotes iliffei* n.sp.) from the marine caves of Bermuda.

Materials and Methods

Euplotes iliffei n.sp. was collected along with many other protozoa in Wonderland Cave. This cave, located in the Hamilton Parish, Bermuda, was previously known as Whitby Cave. The cave was open to the public until the 1940's when it was closed as a commercial tourist cave. A small entrance building gives access to a steep set of stairs which lead to the first room of the cave. This large room contains a sea level lake which is about 60 m long by 12 m wide. A 50 m long underwater passage connects this room to a second smaller air chamber. No known human-sized passageways connect the Wonderland Cave system with Castle Harbour, the nearest body of water which is 420 m from the inland entrance of the cave (14).

Ciliated protozoa were collected in the surface waters of the entrance room of Wonderland Cave using small protozoan traps baited with tuna fish (15). At the time of collection the water temperature ranged from 20.2°–21.2°C and the surface salinity was 12‰. *E. iliffei* was maintained in Millipore filtered sea water (20‰) with wheat grains at 20°C after initial isolation on tuna fish and associated decay bacteria from the protozoan traps.

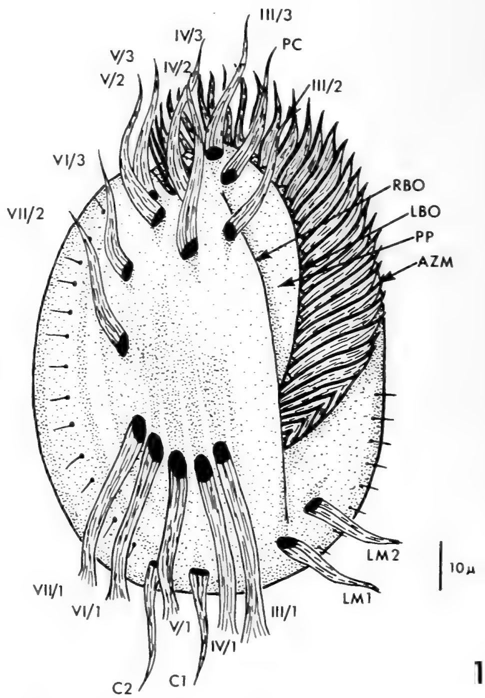
For light microscope observations of cortical ciliary structures and their morphogenesis during cell division, the cells were stained by a modification (16) of the protargol method of Jerka-Dziadosz and Frankel (17). To demonstrate specific cortical structures of the argyrome, preparations were made using Corliss' (18) modification of the Chatton-Lwoff technique of silver impregnation. Borror's nigrosin-$HgCl_2$-formalin stain and fixative (19) was used to observe cortical sculpturing. For determining nuclear shape, the cells were fixed in 2.0% glutaraldehyde, washed in distilled water and afixed to cover slips with Mayer's albumin and feulgen stained following the procedures of DiStephano (20). Drawings were prepared with a Nikon drawing instrument and the terminology of the ventral ciliary structures were based upon the topographical and developmental characteristics as previously outlined for other *Euplotes* species (9,21,22).

Results

Measurements. Total body length 90–115 μm (average 101 μm); body width 70–100 μm (average 85 μm); buccal cavity length 68–88 μm (average 72 μm). (n = 25).

Body Shape (Figs. 1–5). *E. iliffei* is a medium size marine *Euplotes* with an ellipsoidal body shape. The right margin is more convex than the left with the widest point being slightly posterior to the equator of the cell. There is a prominent notch in the upper border of the aboral surface. The posterior end is rounded. The buccal cavity is narrow, extending about ⅗ of the length of the body with the right buccal overture extending from the left most frontoventral cirrus ventro-laterally in a convex curve ending at the anterior most left marginal cirrus. From a mid-point along the right buccal overture, the buccal cavity cuts a medial recess that extends posteriorly to the cytosome. The aboral zone of membranelle (AZM) extends along ⅔ of the left side of the ventral surface in a prominent convex curve turning more dextrally near the cytosome. The AZM archs over the anterior end of the cell with a thin browlike extension bordering the AZM antero-dorsally. On the dorsal surface are 5 prominent single-edged ridges with the left most sixth ridge being double-edged. Each of the ridges are associated with a single kinety. Also a single kinety is associated with a very prominent double-edged ridge that separates the right lateral surface and the ventral surface. On the ventral surface is a wide prominent ridge that extends along the right side and four small ridges that extend anteriorly from between the transverse cirri with the most prominent ridge being between cirri, 1/III and 1/IV. The contractile vacuole pore is ventral, posterior of transverse cirrus 1/VII.

Surface organelles. (Figs. 1–3). There are nine frontoventral, five transverse, two left marginal and two caudal cirri. The number of frontoventral and transverse cirri was constant in over 100 specimens and less than 4% variation in the number of left marginal (1 left marginal cirrus) and caudal (3 caudal cirri) cirri. There is a longitudinal group of endoral cilia in a rectangular field along the posterior part of the buccal cavity. The AZM possesses 28 to 36 membranelles (average = 33). The kinetosomes of the dorsal kinety are variable in number and located in eight kinetal rows (16% of the organisms have 9 kinetal rows). Kinetal row number 1 (found on the left ventrolateral



1

Fig. 1. Ink line diagram of the ventral aspect based on a protargol stained specimen.

Figs. 1–7. Line diagrams of *Euplotes iliffei* n.sp. Key: frontoventral cirri III/2, III/3, IV/2, IV/3, IV/3, V/2, V/3, VI/3, VII/2; PC, paroral cirrus or cirrus II/1; transverse cirri III/1, IV/1, V/1, VI/1, VII/1; right caudal cirri C1, C2; left marginal cirri LM1, LM2; EC, endoral cilia; AZM, adoral zone of membranelles; K1–K8, kinetical rows 1 thru 8. RBO, right buccal overture; LBO, left buccal overture; PP, peristomial plate; CVP, contractile vacuole pore; CS, cytostome; Ma, macronucleus; Mi, micronucleus.

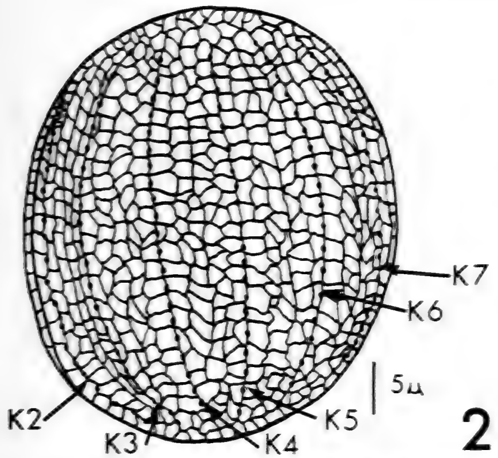


Fig. 2. Dorsal infraciliature, showing position of paired kinetic and argentophilic network.

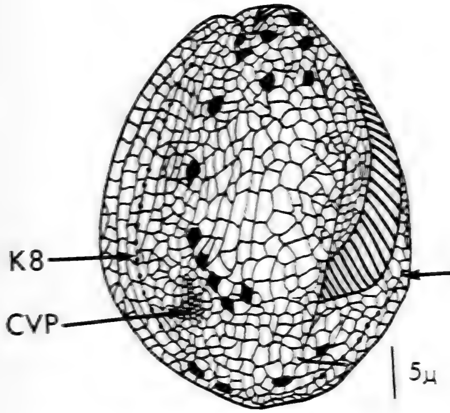


Fig. 3. Ventral infraciliature, indicating ciliary organelles, contractile vacuole pore and argentophilic network.

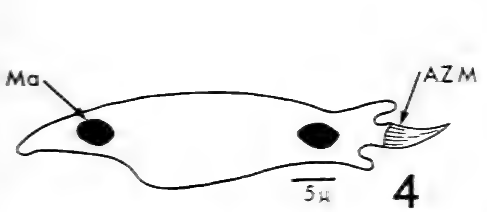


Fig. 4. Optical longitudinal-section at the level of midpoint of the cell.

Fig. 5. Optical cross-section at the level of midpoint of the cell.

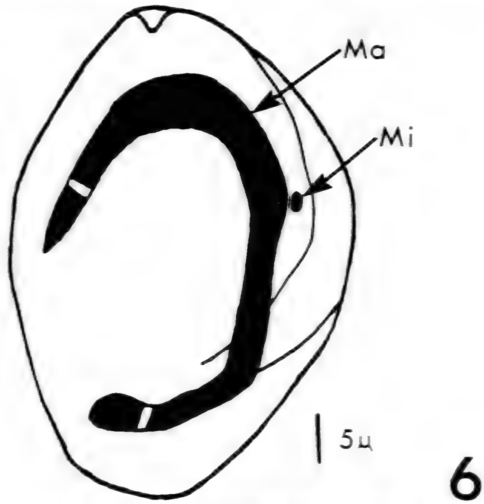


Fig. 6. Micronucleus and macronucleus: replication bands indicated on the macronucleus.

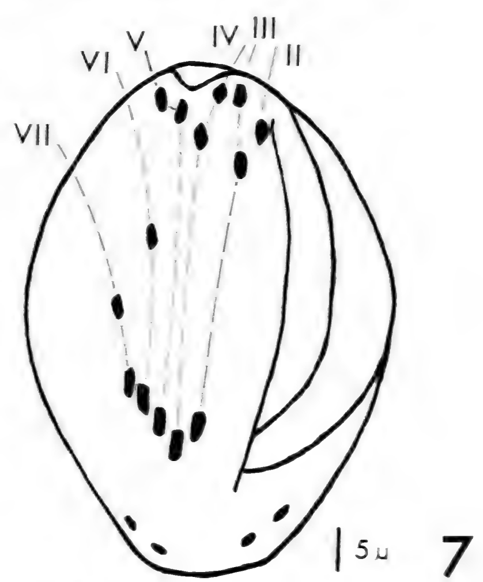


Fig. 7. Diagram of frontoventral cirrus development: occurring during curtical morphogenesis of cell division.

surface just to the left of the AZM) is the shortest row having from 4–10 kinetids of paired kinetosomes (average 7.3). The remaining kinetal rows are numbered consecutively to the cell's right with an increase modal number of kinetids (row 2, 17–24 (average 18.4); row 3, 18–23 (average 20.6); row 4, 17–24 (average 20.8); row 5, 18–23 (average 20.1); row 6, 16–22 (average 19.1); row 7, 16–21 (average 18.0); row 8, 11–17 (average 13.8)).

Silverline system. In wet-silver Chatton-Lwoff preparations, the dorsal interkinetal argentophilic reticulum is of the multiple to complex type consisting of an assemblage of polygenes which have a tendency toward 4 regular rows between the kinetis. The argentophilic meshwork on the ventral surface consists of an irregular assemblage of polygones.

Nuclear configuration. (Fig. 6). The interphase macronucleus is usually C-shaped with the posterior end being flattened and more irregular posterior of the AZM. The micronucleus is small, nearly spherical and located in the upper right half of the cell adjacent to the flattened back of the macronucleus.

Morphogenesis. (Fig. 7). The buccal and frontal ciliature, with the exception of the AXM, develop from an orderly series of ciliary streaks labeled with Roman numerals from the ciliate's left to right. The endoral cilia develop from streak I while the paroral cirrus (II/1) from streak II. The other frontoventral and transverse cirri develop from streaks III–VII. After distinct fields of cirri have formed for both the proter and opisthe from the five original ciliary streaks each field consists of five transverse cirri (III/1–VII/1) and nine frontoventral cirri (II/1 (paroral cirrus), III/2, III/3, IV/2, IV/3, V/2, V/3, VI/3 and VII/2). As the new ciliary structures of the developing daughter cells migrate to their final position and parental cirri are dedifferentiated and resorbed, an equatorial cleavage furrow forms that will result in the cytokinesis.

Discussion

There are 22 described species of *Euplotes* which have a 9 frontoventral cirrotype. Fifteen of these species belong to the type one frontoventral cirrotype pattern where cirrus VI/2 is absent from the frontoventral arrangement (9,21,23). The 9 marine, 2 euryhaline and 4 freshwater species that belong to this group all have a double to complex dorsal argyrome. Several members of this group have 8 or fewer frontoventral cirri. *E. parkei*, when grown in a marine environment, is missing cirrus IV/2 which is present when grown in fresh water (24). *E. poljanskyi* has eight frontoventral cirri with a cirrus missing from row V or VI (25). *E. raikovi*, which has 7 or 8 cirri, is always missing cirri III/2 and IV/2; however in some populations, cirrus VI/2 is present (25) and in others, it is only an argentophilic plaque (21). *E. strelkovi* has eight frontoventral cirri and six transverse cirri which are in the same cirral pattern as *E. raikovi* except that an additional cirral primordia streak develops between streaks IV and V, thus giving rise to the additional frontoventral and transverse cirri (26). *E. parkei* and *E. elegans* are both euryhaline species while *E. affinis*, *E. gracilis*, *E. muscicola* and *E. muscorum* are all from fresh water. Both *E. parkei* and *E. affinis* have a double dorsal argyrome silver system whereas *E. elegans*, *E. gracilis*, *E. muscicola* and *E. muscorum* have a complex dorsal argyrome system where there are from four to many polygonal areas within each interkinetal area. *E. apsheronicus*, *E. bisuleatus*, *E. dogieli*, *E. latus*, *E. nana* and *E. zenkewitchi* are all marine species that have a double argyrome silver-line system. *E. elegans* however is smaller both in length (80 μm) and width (55 μm) and has more oral membranelles (AZM) in it, 40–45. Also in *E. elegans* the central kineties have more dikinetids (40–45) and the dorsal argyrome has many more polygonal areas in each interkinetal zone.

Seven species of *Euplotes* have been described that have the second type of frontoventral cirrotype pattern where cirrus VI/3 is missing. All these species are from freshwater and have double dorsal argyrome system. The silver-line systems have not been described in six undefined but recognizable species; *E. novemcarinata*, *E. rotunda*, *E. terricola*, *E. aberrans*, *E. roscoffensis* and *E. thononensis*. The first three of these species have only been found in freshwater. *E. roscoffensis* has 10 frontoventral cirri while *E. aberrans* has only eight. *E. thononensis*, a marine species, is about the same size as *E. iliffei* and has 9 frontoventral cirri. However *E. thononensis* has a very pronounced peristomial collar and does not have a prominent notch in the upper border of the aboral surface as is seen in *E. iliffei*.

E. identatus (28) described from an intertidal pool in Nassau, Bahamas resembles *E. iliffei* in that it has an anterior notch in the upper border of the dorsal surface. However, *E. identatus* is smaller than *E. iliffei*, has 10 frontoventral cirri and has a 3 polygonal dorsal interkinetal silver-line pattern.

Acknowledgments

T. M. Iliffe, who collected the sample, and described the habitat and for whom the new species was named, was supported by National Science Foundation Grant BSR-8215672. M. van Soeren, R. Power and D. Gibbons assisted with the cave collection. B. F. Hill and E. B. Small identified the protozoa and are the sole authors of the new species of *Euplotes*. The type material has been deposited in the U.S. National Museum. This investigation was supported in part by a National Science Foundation Grant BSR-8400616 to J. O. Corliss and E. B. Small. This paper is Contribution No. 1097 of the Bermuda Biological Station for Research.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 250–257, December 1986

Mathematics as the Grammar of Natural History or The Dream of Pythagoras

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I should like to advance the view that recent discussions in the philosophy of the natural sciences have been incomplete, if not vitiated, by a lack of awareness on the part of many scholars of what is perhaps the single most important feature of natural history, namely its underlying mathematical grammar.

I do not intend here to go into any of the many circumstances to which this situation may be traced. Still, I should like to suggest that too exclusive a concern for the logical side of scientific discourse may have obscured what is most characteristic in any descriptive language, what marks it off from any other having a similar logical structure, namely its own "deep" grammar. However this may be, the fact remains that the logical approach, by itself, is too narrow to reveal the full scope of the role played by mathematical grammars in scientific discourse, just as it has shown itself inadequate in pointing out some of the significant features of the retroductive process as found in scientific discovery, or in bringing out some of the factors that play a role in the choice of particular kinds of explanations, of the sort that Duhem, Hanson or Kuhn, among others, have brought to light.

Because of the relative lack of familiarity with the thesis proposed here, I have thought it best to have a statement of it preceded by a brief exposition of the way in which it actually developed in the context of mechanics during a period of approximately four hundred years, without any claim to either completeness or originality. The main features of the grammar will then be easier to apprehend, and its import for problems of current interest more readily perceived. Consequently, the paper will be divided into two main parts, the first of which presented here, is mostly of a historical nature, while the second will be exclusively thematic and mostly philosophical.

The first part is given to an account of the introduction of mathematics as an essential element in the description of nature, from the beginning of the process to its realization in the context of classical natural history, that is roughly from the early fourteenth century to the end of the eighteenth. The point of it is to see how certain notions that are important to the thesis of this paper came to be manifested as inherent in the nature of description. No pretense is made to either originality or completeness of historical details, my purpose being simply to outline in the briefest fashion the evolution of the role of this aspect of the language of natural history.

Part I: The Historical Background

The introduction of mathematics in the description of nature presents a major problem, namely that of the quantification of what are perceived to be essentially qualitative features. Historically, this has involved two major moves, one the quantification of qualities proper, the other the development of a suitable mathematical language for their representation.

(*1*) *The Quantification of Qualities*

The quantification of the qualitative features of nature was realized in several stages:

(a) First came the selection of those aspects of nature that were in fact measurable, since these were *ipso facto* quantifiable. As a result, these measurable features became fundamental to the description of nature, and everything else was to be reduced to, or analyzed in terms of them. For example distances, which could be measured directly, gave point to the belief that length is an integral constituent of the intelligibility of nature. However, color could not be measured directly, and so could not play a similar role in the architecture of nature; at best it would be analyzable in terms of some fundamental qualities or, this failing, would be ranked an occult feature of the perceived world and remain outside the domain of science(1). Considering further that such magnitudes were separately measurable, a set of independent entities was thereby defined, providing the basic dimensions for the description of nature.

(b) Another important move had to do with the representation of each of these fundamental dimensions, since the ultimate objective is not simply to measure individual observables, but to describe the observed behavior of nature in terms of its underlying mathematical structure.

As it turned out, this demanded a conceptual revolution relative to the cultural context in which the enterprise germinated, leading to such historically important distinctions as that between primary and secondary qualities. It also led to the abandonment of the view that all qualitative changes were essential ones, on the grounds that otherwise two different degrees of a given quality, such as warmth or whiteness, could not be compared by means of a common measure, a view clearly contrary to facts(2).

Further, the representation of qualitative measurements required a clear understanding of the way in which discrete ensembles such as those provided by the results of measurements, could be embedded in a continuum. This key move was made by the Franciscan nominalists of the fourteenth century, more especially by Mayronnes, who proposed that all degrees of quality should be represented in the classical Greek manner, namely as ratios of two magnitudes having an identical nature, without need of further specification. The positing of this "Principle of Homogeneity", needed to compare different magnitudes thus neatly by-passed all the issues raised by the conflicting claims of the metaphysicians of the period, and thereby provided the first effective criterion of demarcation(3).

That numbers can be represented by ratios of lines, whether commensurable or not, had been known long before Aristotle, going back to the days of the early Pythagoreans[4]. It is however the authority of Aristotle that was invoked, if for no better reason that more reliable ancient authorities were not generally available to schoolmen working on these problems[5]. In any case, the principle of the linear representation of degrees of magnitude became established, and was later considerably generalized by N. Oresme, who is regarded by some as the originator of the notion of coordinate systems[6]. This claim is not without its weak points, despite the impressive array of authorities behind it, although it must be said that there are distinguished dissenters as well[7]. One can argue that Oresme did not have a true coordinate system in the sense that this expression has taken in analytical geometry, the only one that matters here. What Oresme has developed is the principle of the diagram, or chart, of the sort used to compare various states of affairs at different times or places, such as steel production in different parts of the world, or shares of a market taken by competing companies, etc. There are two reasons for this view. In the first place, the abscissa (latitude as Oresme calls it) does not function analytically, nor even as a variable axis in which the ordinate (or longitude) does. Secondly, the curve linking the variable altitudes of the ordinates does not represent a functional dependence of the two coordinated axes, but is simply a symbolic representation of a qualitative profile, not unlike that of a cameo used in the manner of the eighteenth century "physionomistes" to represent the kinds of features thought to be symptomatic of different human types (e.g. the musician, mathematician, criminal, etc). In such diagrams, the profile of the ordinates is used as an instrument of identification rather than as an expression of an internal structure which would characterise the phenomenon. The difference is crucial, and it would take nearly another two hundred years before the notion of a function appeared with Viete in the context of algebraic theory. It would take even longer before Descartes could introduce true coordinates, needed both for the analytical reduction of geometrical curves and for the application of mathematical functions to the observable features of ordinary experience[8].

(2) *The Development of Algebraic Geometry*

The next important step has to do with the actual development of mathematics beyond the level of achievement attained by the ancient Greeks and by the Arabs, the knowledge of which was transmitted to medieval Europe through translations systematically undertaken in Sicily and in northern Spain under various aegises[9]. This too would amount to a conceptual revolution. The reason being that the Greeks had a synthetic type of geometry, meaning a geometry without algebraic substructures, so that the geometrical figures had to be operated on directly rather than through the mediation of analytical instruments[10]. Another aspect of this revolution is traceable to the fact that the algebra of the Arabs was, at best, numerical or directly representative of geometrical magnitudes, with the consequent emphasis on the special case under study, rather than on the more general considerations we associate today with the notion of an algebra[11].

The revolutionary developments that were to follow during the Renaissance, up to and including the seventeenth century, took place in three logically distinguishable stages. First came the development of analysis by Viete, then the development of analytical geometry, more difficult to attribute to any one writer, and last the application of the methods of algebraic analysis to the study of geometry analytically articulated in terms of coordinates. This last step can be fairly attributed to both Fermat and Descartes, who worked independently on this, although Descartes is rightly considered the more important of the two in this particular respect, and usually given the official paternity of the new geometry[12]. In as much as the decisive steps that transformed the synthetic geometry of the Greeks into the analytical geometry of Descartes are difficult to imagine without the prior availability of the notion of function[13], and since, in point of historical fact, it followed its appearance by nearly half a century, it is best to begin with the work of F. Viete (1540–1603).

(a) The Development of Analysis

Viete began innocently enough by systematically replacing all the magnitudes ordinarily found in the numerical algebras inherited from the Arabs by letters, reserving vowels for the unknowns[14]. This simple move, systematically carried out, had momentous consequences. It revealed for the first time, in a conspicuous if not always in a perspicuous way, the existence of algebraic sentences as mathematical objects of a new kind, heretofore hidden from view by the particular magnitudes that were in evidence in the traditional notations. By taking away the magnitudes of the ancient geometers and algebraists, Viete came to the realization that 'numerical algebra' was no longer the right name for what he was doing and changed it, first to 'algebra speciosa', and later to the more aptly descriptive expression of 'analysis', a name that has been retained to this day[15].

Viete's move had two major consequences. In the first place, it gave prominence to the notion of a variable as a sign made to represent any one of a number of individuals of a certain kind, by emphasizing the roles they play in the sentence. The sentence resulting from the substitution of letters for magnitudes is itself a variable, namely a sentential form that may be shared by countless algebraic expressions, a matrix of possible structures[16]. Secondly, Viete's move made overt for the first time the existence of a fundamental difference between the two kinds of variables: those whose values are determined directly by reference to a range of individuals, and those whose values result from the determination of the former. In the first case, we have independent variables, and in the second, dependent ones.

For instance, the algebraic expression '$f(xy)$: $ax + by + c$' is a complex expression made up of simple elements, the letters (the individual vowels and consonants), and the syncategorematic signs which symbolize the sort of relation that the letters bear to one another. In this manner, the distinction between the sentential form proper, which is dependent on the nature and arrangement of its parts, and its elements is immediately apparent: it represents clearly the relation between the function (the dependent variable) and its arguments (the independent variables). In this sense, the algebraic expression may be said to be "perspicuous": it shows what it says[17].

Two things are implicit in the dependence of the function on its arguments: first, a value being determined in the domain of each individual variable, a well formed sentence results having the same form (grammatical structure) as that of the dependent variable. Second, all independent variables save one being fixed in some manner, the resulting sentential form may be used to "pick out" the value of the remaining variable, thereby exhibiting the fundamental relation that exists between the dependent variable, which has sense, and its independent elements which refer to elements of the domain of interpretation[18].

(b) The Development of Analytical Geometry

Analytical geometry may be defined as the study of geometrical figures considered as loci of points bearing some characteristic relation to other loci or axes. Defined in this manner, analytical geometry originated with the Greeks, and more particularly with Apollonius of Perga, although some have traced it much earlier, to Aristaeos[19].

The original impetus for this sort of approach may well have been the production of curves by mechanical means, that is to say by moving points constrained in some characteristic manner. Yet it does not appear that the Greeks extended this analytical approach to the whole of geometry, although it was applied to a number of important problems, such as those of the so-called 'solid loci' (the conics), and somewhat systematized, witness Pappus of Alexandria's "Treasury of Analysis"[(20)].

It is only with the greater dissemination of Pappus' work following the invention of printing, that the analytical method begins to be used in earnest by the geometers of the sixteenth century, and applied to problems that had, up to then, fairly resited solution, as well as to new problems of increasing complexity[(21)]. Once it was clearly perceived that geometric figures were loci defined in relation to axes (straights) or to foci (points), the implication of the work done by Viete in algebraic analysis could not for long escape the more perceptive of the new geometers, beginning with Viete himself[(22)]. From that time on, the development of analytic geometry becomes inseparable from that of algebraic geometry until, with the work of Fermat and Descartes, the two cease to be distinguishable. It is best therefore to pass now to the consideration of analytical geometry in its algebraic form.

(c) The Development of Algebraic Geometry

The expression 'algebraic geometry' is meant to apply specifically to the application of the new methods of Viete's analysis to geometrical problems considered in the analytical manner mentioned above, and originally found in the works of Pappus of Alexandria[(23)].

Despite some early work in this area by Viete, and further extensive investigations by Fermat, it is only with the publication of Descartes' "Geometrie" in 1637 that algebraic geometry comes into its own[(24)]. There are several reasons for this.

The first one is a consequence of the systematic introduction of coordinates to refer to any point in space. For example, in 3-space, a point P will be identified by means of a triad of numbers (x_1, x_2, x_3) in an expression such as $P(x_1, x_2, x_3)$. This move resulted in the effective arithmetization of space, and although Descartes made use of it mostly to analyze curves in two dimensions, the principle was acquired that geometric space provides the algebraist with a natural domain of interpretation for coordinated sets of numbers.

The second reason, the result of various steps, including the abandonment of the principle of homogeneity first introduced by F. de Mayronnes, later modified by Viete and used in that form by Fermat[(25)], is that Descartes took seriously functions which up to then had been considered to be indeterminate, and therefore of no geometrical significance[(26)]. To be more specific, Descartes looked upon functions in two unknowns, of the form $F(x, y) = 0$, as algebraic expressions of loci of points whose coordinates, represented by x and y, were constrained in their independent variations by the relation symbolized by the function $F(x, y)$. This enabled Descartes to give an algebraic treatment of the solid loci, i.e. of the conics of Pappus, which, it will turn out, are the only paths allowed by the inverse square law of central force operative in the cases studied by Kepler and by Galileo, and later reduced by the gravitational hypothesis of Newton.

These two reasons, more than any other factor, opened up an entirely new field of inquiry, namely rational mechanics, and for the first time provided the natural philosopher with the grammatical means to develop a science along the lines first laid down by the Pythagoreans, and imperfectly exemplified in the works of the ancient masters, Euclid, Archimedes and Ptolemaos, in which physical nature was described in terms of its assumed underlying mathematical structure.

The subsequent development of analytical geometry proper lie outside the area of our immediate concern since it had little impact on the language of physics, at least in the period of the so-called "scientific revolution"[27]. Of greater interest is the development of more powerful methods of analysis by Newton and Leibniz. Their importance for the study of geometric curves can be traced to the considerable expansion and refinement of the means of effecting the transformation of functional expressions into new forms by applying rules of great simplicity. These analytical means resulted in very sensitive instruments for the determination of the properties of curves, including their curvatures, torsions, discontinuities, their behavior in the neighbourhood of points of singularity, etc. These are of interest to physical scientists concerned with the paths of particles, with the equipotential surfaces and the gradients of force fields, with the properties of fluids at rest and in motion, as well as with the fitting of experimentally determined points onto a suitable curve[28]. They also provided tools for the study of bodies, both rigid and deformable, that was to revolutionize celestial mechanics no less than the physics of matter. It is sufficient to evoke the great names of Euler, the Bernouillis, Maupertuis, Lagrange, Hamilton, Carnot, Clausius, Gauss, Maxwell, Fourier, among so many others, to realize the extreme fecundity of the new analytical methods, and the scope of their applications.

There is yet another feature of the new analysis that ought to be mentioned because of the importance it had for the realization of an old ideal of the ancient Pythagoreans and of their spiritual heirs who made the scientific revolution, that of describing nature in terms of its assumed underlying mathematical structure.

Mention has been made of the fact that the new analysis is distinctive, compared to the older mathematics, by the means it provides for the transformation of mathematical sentences while preserving their truth conditions. Such transformational properties make it possible for one to explore and describe in a more explicit and perspicuous manner those properties of the functions under study that are of particular interest in a given context. Lagrange would use these transformational properties to weave a continuous web of syntactical relations as the fundamental grammar of a new language for the description of the behavior of particles, a rational mechanics and, by way of extension, a language for the physics of motion. He was quite aware of the importance of the resulting interconnectedness of the different sentences of the language and was moved to claim, with some satisfaction, that one would not find a single geometrical diagram in his whole mechanics, but only the equation of the new analysis[29]. In his "Mechanique Analytique", Lagrange strove to make apparent the derivational nature of the language, and by its means, the axiomatic and deductive character of the science of mechanics in a way that neither Archimedes nor Newton could. He did this by reducing the multiplicity of laws to a very few mathematical principles, the most important of which was the so-called "principle of virtual forces". As a result, for the first time, the *sentential form* of the laws was made to depend explicitly on that of the assumptions, giving these the status of ancestral relations in the new genetic process of sentence formation[30].

This represents a significant development in the evolution of the language of science, the "Mechanique" being the first modern and rigorous treatment of this fundamental discipline. Indeed, there is a greater discontinuity in this respect between the works of Lagrange and those of Newton than that which exists between the latter and Archimedes' works, while contemporary treatments hardly differ from Lagrange's on that score. And thus the full scope and import of the mathematization of the descriptive language of science is revealed. It is that mathematics provides the fundamental web of relations in terms of which physical reality is charted, and its essential properties made apparent. In this manner, mathematics appears, for the first time at the end of the eighteenth century, not simply as a tool for the quantification of observables, nor as a kind of short hand to help classify natural phenomena, though it does all those things. But also, and more importantly, as constitutive of the very structure of these phenomena. By way of consequence, it also appears as the grammar descriptive of the structure of the reality it is said to mirror. This notion will be attended to in the second part.

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2. **P. Duhem:** "Le Systeme du Monde" (Paris, Hermann, 1913–1859), **6,** 451 ff.
3. **F. de Mayronnes:** "In primum Sententiarum Scriptum Conflatus Nominatum", Dist. xviii, quaest. ii, art.i. Quoted in Duhem: Op. Cit., **7,** 512–513.
   . . . . "l'augmentation [d'une qualite] se fait necessairement a l'aide des choses en lesquelles, necessairement se resout ce qui a ete augmente; or *ceci se resout en parties homogenes*, c'est ce que montre la division de la ligne, qui est une resolution; *il faut donc que, de meme facon, l'accroissement d'intensite se fasse par le moyen de degres*" (emphasis added).
   M. Clagett: "Nicole Oresme and the Medieval Geometry of Qualities and Motions" (University of Wisconsin Press, 1968), 165–167.
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   D. J. Struick (ed): "A Source Book in Mathematics, 1200–1800", 76–77
   D'Alembert was to make a similar point, but in the context of a fully developed notion of analytical function of two variables, where it is no longer objectionable. Cf. d'Alembert: "Traite de Dynamique" (Paris, 1743), vij–viij; 16n (in the 1796 ed). Similarly, J. L. Lagrange in his "Traite des Fonctions Analytiques" (Paris 1813), 316–317.
4. **T. Heath:** "A History of Greek Mathematics", Vol. I, 84–91. The discovery of irrational numbers, in connection with that of the incommensurability of the diagonal of the square in relation to any of its sides is generally attributed to the school of Pythagoras.
5. **M. Clagett:** "The Science of Mechanics in the Middle-Ages" (University of Wisconsin Press, 1961), 333.
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9. **E. Grant:** "Physical Science in the Middle-Ages" (New York, J. Wiley, 19), 13–17
   A. C. Crombie: "From Augustine to Galileo. . . .", 23–30.
10. **J. L. Coolidge:** "A History of Geometrical Methods", viij, 127.
11. **J. L. Coolidge:** Op. Cit. 32
12. **M. S. Mahoney:** "The Mathematical Career of Pierre de Fermat" (Princeton University Press, 1973), 72 ff.
    J. L. Coolidge: Op. Cit. 126–128.
13. Some scholars, such as Coolidge (Op. Cit., 119), would make analytical geometry in this sense go back to Menaechmus. However one may view this, it does not materially affect the picture proposed here, which is a simple sketch of the moves that were *de facto* influential in the process of mathematization of physical science at the time of the scientific revolution. These two sides of the history of mathematics are different, and should not be conflated.

14. I say "systematically replaced" since the spotty and sporadic introduction of letters for some special purpose antedates Viete by nearly a millenium, if not more. The importance of Viete lies in the fact that he did it systematically. Cf. F. Cajori: "History of Mathematics", 139.
15. **D.J. Struik:** "A Source Book in Mathematics, 1200–1800", 75.
16. **L. Wittgenstein:** "Tractatus Logico-Philosophicus" (London, Routledge, Kegan Paul, 1922), 2.033.
17. **G. Frege:** "What is a Function?" in: "Translations from the philosophical writings of G. Frege" (Oxford, Blackwell, 1952), 107–116.
18. The existence of referents is not a foregone conclusion, and may have to be demonstrated. Cf. e.g. G. Frege: "The foundations of Arithmetic" (Oxford, Blackwell, 1953), 107–108.
19. **T. Heath:** "A History of Greek Mathematics" (Oxford, 1921), Vol. I, 438; Vol. 2, 118–119.
20. **T.Heath:** Op. Cit., **2,** 399 ff.
21. **A. C.Crombie:** "Augustine to Galileo. . . .", 281
22. **F. Cajori:** "History of Mathematics", 142
23. **J. L. Coolidge:** Op. Cit., 125–126
24. **Cf. e.g. A. D. Aleksandov, A. N. Kolmogorov, M. A. Lavrent'ev:** "Mathematics" (Moska, 1956). English trans.: S. H. Gould and T. Bartha: (MIT, 1963), **I,** 184–186.
25. **F. de Mayronnes,** quoted in P. Duhem: Op. Cit., **7,** 512.
    J. L. Coolidge: Op. Cit., 126.
    D. J. Struick: Op. Cit., 150.
26. **J. L. Coolidge,** Ibid.
    A. C. Crombie: "Augustine to Galileo. . . .", 282.
27. The advent of non-Euclidean geometries in the nineteenth century was to have a major impact on the subsequent development of field theories, and especially on that of geometrodynamics, beginning with Einstein's general theory of relativity. Cf. e.g. J. A. Wheeler: "Geometrodynamics", Italian Physical Society. Academic Press NY, 1962.
28. Cf. infra
29. **J. L. Lagrange:** "Mechanique Analitique" (Paris, 1785), preface.
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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 257–260, December 1986

Aging and Cognition: What Is Saved and What Is Lost?

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As people grow older, they notice apparent declines in their own mental functioning, and there is remarkable similarity across people in the particular changes reported. Almost everyone notices increased word- and name-finding problems, encountering more and more often those frustrating situations in which a well-known word or person's name is on the tip-of-the-tongue, but not quite speakable. Very common, too, are reports of difficulties in learning the names of new acquaintances or remembering mundane details, such as what one meant to buy at the grocery store. Such apparent cognitive declines present only half of the story, however, because there are other abilities that appear to improve or, at least, remain constant. For example, aging people rarely complain of losing "old" memories of the distant past; memories of one's first love or the meaning of an encountered word are unlikely to fade in old age.

For the last eight years or so, my undergraduate assistants and I have been applying the theories and methods of cognitive psychology (cf. Howard, 1983a) to the study of human aging. The broad goal has been to differentiate those aspects of cognition that change in the course of normal aging from those that do not. Although emphasis in the past has usually been on what is lost, investigating what is saved as well provides a more accurate theoretical account of cognitive aging. In addition, knowing what is saved might make it possible to help elderly people tap such abilities to compensate for what is failing. Finally, knowing what is saved in normal aging provides a baseline for distinguishing it from pathological aging. For example, early detection of Alzheimer's Disease would be more accurate if we could find an ability that remains intact in normal aging, but is lost in the early stages of the disease.

Looking up or "activating" word meaning. Our first studies of aging (Howard, Lasaga, & McAndrews, 1980; Howard, McAndrews, & Lasaga, 1981; Howard, 1983b) were motivated by influential processing-deficit theories which suggested that the memory difficulties that accompany normal aging are due to a decline in the extent to which people look up or "activate" in memory the meaning of words they encounter, a process that is often called *semantic activation.* This seemed a reasonable hypothesis, because it is clear that among young adults at least, one of the best predictors of whether or not a person will remember having encountered a given word in a study list is the extent to which the person looked up the meaning of the word in memory. For example, people are much more likely to recall that the word "dog" was encountered earlier if they had to make a semantic judgement about the word during study (i.e., Is this an animal?) than if they had made a sound-based judgment (i.e., Does this rhyme with fog?). Thus, processing-deficit theory proposed that elderly adults are less likely than young to look up meaning spontaneously, and this leads them to have poorer memory.

However, by using more direct methods than had heretofore been applied to aging, we were able to show that the same elderly people who suffer memory deficits when compared with younger people are not deficient in semantic activation. One kind of evidence for this comes from our finding that semantic priming effects are just as large among elderly as young people. *Semantic priming* refers to the fact that processing a given word facilitates (i.e., primes) subsequent processing of a semantically related word. For example, if people are asked to make speeded decisions about whether or not a string of letters is a word, they make an affirmative decision to the string "dog" more rapidly if they just saw the word "cat" than if they just saw the word "sew." Thus, even though people were not asked the meaning of the words, we can tell that they have looked it up nonetheless, since the meaning is influencing their response times. The fact that elderly people show semantic priming effects equal to young people—even though these same elderly people are much poorer than the young at later remembering the words (e.g., "dog, sew") about which they made decisions—places constraints on any form of processing-deficit theory. In fact, subsequent research (Nebes, Martin, & Horn, 1984) at the University of Pittsburgh has shown that such semantic activation remains intact even among those suffering from Alzheimer's Disease.

The speed of mental processes. In subsequent research we have found that although there is age-constancy in the *likelihood* that meaning will be looked up, there is a decline with age in the *speed* with which this is accomplished (Howard, Shaw, & Heisey, 1986). This conclusion comes from studies in which we vary the duration between onset of a prime word (to which the person need make no response at all) and onset of a target word about which a speeded lexical decision must be made by responding "yes" if the target is a word and "no" otherwise. We find that young adults reveal semantic priming at intervals between the prime and the target as short as one-sixth of a second, but elderly individuals require longer durations in order for the meaning of the prime word to influence response time to the target. This suggests that with normal aging there is a slowing in the speed with which word meaning can be activated from memory. This slower semantic activation could contribute to the difficulties some elderly people experience in both remembering and understanding language. For example, in normal conversation, speech is usually rapid and often unclear (a fact that becomes obvious when we listen to people converse in a foreign language). Rapid semantic activation helps people to deal with this ambiguity by enabling them to use semantic context quickly (and often unconsciously) to determine what is likely to occur next. Any age-related slowing in the speed of such activation would make it difficult for the elderly person to comprehend rapid speech, particularly when coupled with the sensory deficits that accompany advancing age.

Explicit and implicit memory. Our most recent work calls attention to the potential importance of the distinction between measures of explicit versus implicit memory. Tests of *explicit* memory require a conscious report of remembering, and so tap what has been called *memory-with-awareness.* In contrast, tests of implicit memory do not require such an introspective report and are said to tap *memory-without-awareness.* To illustrate, people might be asked to study a list of words. Explicit memory for the words could be assessed via the usual recall and recognition tasks; people would be asked, "What words occurred in the list you just studied?" or "Did this word occur in the list you just studied?" In contrast implicit memory might be tapped by presenting word fragments (e.g., STU____) and asking people to complete them in the first way that comes to mind. Finding that people are more likely to complete the above fragment with "DENT" if they have just studied the word STUDENT than if they have not would provide evidence of implicit memory. Extensive research has shown that amnesia patients often reveal completely normal implicit memory even when their explicit memory is severely impaired (cf. Schacter, 1985). Despite this evidence that implicit and explicit memory act differently, most previous research on normal aging has relied solely upon explicit measures.

In our most recent work (Howard, Heisey, & Shaw, 1986; Howard, in press) we have been comparing the aging of implicit and explicit memory. We are finding tht even when explicit tests yield large age differences favoring young adults, implicit tests of memory for the same material often reveal age equivalence. Although we are only beginning this work, it is clear already that more of memory functioning is saved in normal aging than explicit tests reveal. This presents the empirical challenge of comparing implicit and explicit memory more fully, the theoretical challenge of determining how this distinction can be built into models of cognition and aging, and the practical challenge of determining whether there is any way in which people can learn to tap these unconscious memories to help compensate for failing explicit memory.

Summary. We have been working in the relatively new field of cognitive gerontology, applying theories and methods of contemporary cognitive psychology in an attempt to differentiate those mental processes that change in the course of normal aging from those that do not. We find that although there is age constancy in the tendency to look up the meaning of encountered stimuli, there is a decrease with age in the speed with which this is accomplished—a slowing that likely affects both remembering and comprehending language. We also find that implicit memory tests indicate that much more of memory is saved than the more frequently used explicit tests have revealed.

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Acknowledgments

This research was supported by Grants R23 AG00713 and R01 AG02751 awarded by the National Institute on Aging. I have been fortunate to have been assisted by a number of fine undergraduate students over the years. The contributions of some of these people are reflected by the fact of their joint authorship on the papers cited here. In addition, I am happy to acknowledge the excellent work of Maria Acosta, Jeff Amerman, Stephen Burns, Lisa Conomy, Margie DelGreco, Martha Farmelo, Astrid Fry, Wendy Eicholzer, Christina Emanuel, Holly Gomes, Peter Gordon, Marijean Hosking, Elizabeth Jones, Carolyn Marfizo, Michelle Millis, Mary Beth Quig, Mitch Sommers, Cathy Stanger, Tom Steif, Lisa Swartz, Anne Watson, Paige Wilhite, Ed Wisniewski, and Bob Zozus. I am also grateful to Jim Howard for his advice on all of my research, and to the people of all ages who have volunteered to participate in our studies.

Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 261–262, December 1986

The Scientific Achievement Awards of the Academy: 1984 and 1985

Richard K. Cook

Chairman of the Awards Committee, Washington Academy of Sciences

The Awards are presented annually to young scientists in the Washington, D.C. area. This program was started in 1939 to reognize young scientists for "noteworthy discovery, accomplishment, or publication in the Biological, Physical, and Engineering Sciences." The Awards now recognize and commend scientific work of high merit and distinction in the following scientific areas: Biological, Physical, Engineering, Mathematics and Computer, and Behavioral Sciences. In the Teaching of Science, the Leo Schubert Award and Bernice G. Lamberton Award.

In the autum of each year the Academy announces publicly its Awards program for that year. Nominations are invited, and are usually made by sponsors who are familiar with the scientific work of the candidates. The nominee scientist and teachers of science must be resident within 50 miles of the White House in Washington. The Awards Committee then evaluates the works of those nominated and recommends the successful candidates to the Executive Committee. Each Award consists of a Certificate of Scientific Achievement and election to Fellowship in the Academy.

1984 Awards for Scientific Achievement

These were presented at the Academy's meeting at the American University in Washington, D.C. on April 18, 1985, to the following five scientists and teachers.

Theodore R. Kirkpatrick of the Institute for Physical Science and Technology and the Department of Physics and Astronomy at the University of Maryland. The Physical Sciences Award for exceptional contributions to the statistical theory of fluids.

Warner Greene of the National Cancer Institute at the National Institutes of Health. The Biological Sciences Award for major contributions to immunology and oncology.

James M. Wallace of the Department of Mechanical Engineering at the University of Maryland. The Engineering Sciences Award for ingenious experiments on the structure of turbulent shear flows.

Joseph D. Hagman of the U.S. Army Research Institute. The Behavioral Sciences Award for notable contributions to the psychology of skill acquisition.

Linda Berg of the Department of Botany at the University of Maryland. The

Leo Schubert Award in the Teaching of Science, for excellent teaching and development of teaching methods in botany.

1985 Awards for Scientific Achievement

These were presented at the Academy's meeting at the Cosmos Club in Washington, D.C. on April 17, 1986, to the following seven scientists and teachers.

Warren E. Pickett, Condensed Matter Physics Branch U.S. Naval Research Laboratory. The Physical Sciences Award for pioneering researches into the theory of the basic properties of solids.

Michael MacDonell, Department of Microbiology at the University of Maryland. The Biological Sciences Award for development of a new basis for tracking the evolution of bacterial species.

Stuart D. Jessup, David W. Taylor Naval Ship Research and Development Center. The Engineering Sciences Award for new accurate measurements of unsteady water pressure on ship propellers.

Robert W. Jernigan, Department of Mathematics, Statistics, and Computer Science at The American University. The Mathematics and Computer Sciences Award for useful statistical researches applicable to time series models of the environment.

Darlene V. Howard, Department of Psychology at Georgetown University. The Behavioral Sciences Award for contributions to cognitive science and the psychology of aging.

Marylin Krupsaw, University of the District of Columbia. The Leo Schubert Award in the Teaching of Science, for outstanding achievements and contributions to science education.

James D. Sproull, Jr., McLean High School in Virginia. The Berenice G. Lamberton Award in the Teaching of Science, for a nationally recognized program uniting textbook science with direct experience.

Acknowledgments

The Awards Committee is made up of several members and a chairman, all fellows of the Academy. Each member serves as chair of a panel which evaluates the nominations in one of the seven scientific areas of the Awards. In 1984 the Panel Chairs were Mary H. Aldrich, Joan R. Rosenblatt, Frank R. Yekovich, Cyrus R. Creveling, Joseph R. Morris, and Richard K. Cook. In 1985 the Panel Chairs were Mary H. Aldrich, Ralph I. Cole, Abolgassem Ghaffari, Edward J. Finn, Donald O. Buttermore, Cyrus R. Creveling, and Frank R. Yekovich. The Academy owes its thanks to the Panel chairs and their colleagues for their devoted efforts in arriving at the winners of the Awards.

Richard K. Cook, Chairman
Awards Committee

Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 263–266, December 1986

Development of a Phylogenetic Taxonomy for the Eubacteria

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Introduction

Ribosomal RNAs (rRNAs) are small nucleic acids which, in prokaryotes, range in size from 120 bases (5S rRNA) to slightly more than 2900 bases (23S rRNA). These complex with ribosomal proteins to form the ribosome, which is the protein synthesis apparatus of biological cells. Since the ribosome is a fundamental feature of all known forms of life, comparative analysis of it and its components is able to provide information of immense importance to investigators involved with the determination of evolutionary relationships among species. This information is encoded in the sequence of nucleotide bases which comprise the ribosomal RNAs, which are among the most highly conserved biological molecules known. It is precisely this conservancy that makes ribosomal RNA sequences particularly interesting to evolutionary biologists, since in the study of prokaryotic evolution, comparative sequence analysis of ribosomal RNAs can provide a direct measure of the evolutionary distances among species.

Advances in the field of molecular biology during the past decade and a half have resulted in the development of techniques for determining the nucleotide base sequences of RNAs. The 5S rRNA molecule is the smallest of the prokaryotic ribosomal RNAs and is relatively easy to sequence. As a consequence, substantial numbers of 5S rRNA sequences have been determined and reported in the literature (Erdmann and Wolters, 1986). Comparisons among these have proved particularly relevant to the construction of natural phylogenies of bacteria (Sogin et al, 1972; Luehrsen and Fox, 1981; Dekio et al, 1984; MacDonell and Colwell, 1985).

Initially, attempts were made to employ comparative sequence analysis of 5S rRNAs to solve evolutionary relationships among diverse prokaryotic groups, such as Gram-negative and Gram-positive eubacteria, cyanobacteria, the mycoplasmas, etc. However, the relatively small sampling of bases in 5S rRNAs was soon found to be inadequate for the mapping of distant evolutionary relationships. It is now realized that the strength of 5S rRNA sequences, as phylogenetic indi-

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cators, is in the inferrence of evolutionary relationships at or within the family level (MacDonell and Colwell, 1985). More fundamental evolutionary relationships, such as those between the archaebacteria and eubacteria have been determined through the use of a related technique involving comparisons among 16S rRNA oligomer catalogs (Woese et al, 1985). From the results of these studies were constructed evolutionary trees which have been instrumental in gaining an understanding of the complex evolutionary history of prokaryotic species. An overview of the early work in this field has been published (Stackebrandt and Woese, 1984).

Inferring Evolutionary Relationships from Ribosomal RNA Sequences.

The approach we employed in the inferrence of phylogenetic relationships from 5S rRNA sequences differs from previous approaches in several important respects. We wished to demonstrate that fine detail of the evolutionary relationships within a family of closely related species could be deduced from comparisons among 5S rRNA sequences. Therefore, 5S rRNAs were purified from 36 species of the eubacterial family Vibrionaceae. The sequences of these RNAs were determined enzymatially and a difference matrix was constructed from pairwise comparisons of the sequences. A computer program KITCH (PHYLIP: Phylogeny Inferrence Package, J. Felsenstein, Univ. Washington) was used to construct an evolutionary tree from the difference matrix data.

After determining approximately thirty 5S rRNA sequences, however, we became aware of a flaw in the method by which ribosomal RNA sequences were clustered. Specifically, it had been assumed that there is an equal likelihood of mutation at every base position in ribosomal RNAs. Consequently, mismatches between pairs of RNA sequences were treated by clustering algorithms as if they had equal significance, regardless of location. A position-wise analysis of the mutation frequency in Gram-negative eubacterial 5S rRNA sequences, however, indicated that there are "hot-spots" in 5S rRNA sequences, characterized by mutation frequencies several times greater than in flanking regions (MacDonell et al, 1986a). In other words, the tendency for mutations to occur at different locations in the 5S rRNA molecule is quite unequal. Actually, the existence of unequal rates of mutation had been recognized for several years. This had given rise to the concept of "group-specific signatures", referring to the most highly variable regions in the sequence which could be used to identify specific groups of closely related species with which the "signature sequence" was associated. For several years, however, there were too few 5S rRNA sequences to allow for the empirical determination of the extent of variability (or conservancy) at each position. With the addition of more than fifty 5S rRNA sequences determined in our laboratory, the total collection of Gram-negative eubacterial sequences increased to seventy two, a sufficient sampling to allow us to determine the position-wise relative frequency of mutation in 5S rRNAs of that group of bacteria (MacDonell et al, 1986a).

Graphical Representation of Evolutionary Interrelationships

Ordinarily, evolutionary relationships among species are depicted as two dimensional evolutionary trees in which the branch lengths represent relative evolutionary distances. Unfortunately, the planar representation of multivariate data, such as evolutionary relationships, requires a number of compromises to be made as complexity, viz., number of species, increases. This is due to an averaging process characteristic of clustering algorithms, and results in a loss of overall resolution. Since the work in which we were engaged involved the construction of a phylogenetically-rooted taxonomy of the eubacterial family Vibrionaceae, we required an accurate method for graphically representing the complex interrelationships among a number of closely related species. We decided to augment the conventional evolutionary tree clustering approach through the use of a modified principal components method to graphically portray phylogenetic relationships encoded in the 5S rRNAs of bacterial species (MacDonell et al, 1986b). Principal components analysis is traditionally used to reduce the total number of dimensions needed to view multivariate data sets (Johnson and Wichern, 1981). Our approach strayed from the conventional usage of principal components analysis in that symmetric, i.e. square, distance matrices were substituted for the standard variable and observation format. The result of this modification is that the distinction is lost between row and column eigenvectors. Virtually the same approach was described by Gower (1966) for use with numerical taxonomies, which he called Principal Coordinates Analysis.

A Phylogenetic Taxonomy for the Genus *Vibrio*.

The approach we have taken toward drawing inferrences on the evolutionary relationships among a group of closely related prokaryotic species, based on 5S rRNA data, is best illustrated using species of the marine eubacterial genus *Vibrio*. Through comparative sequence analysis of 5S rRNAs purified from *Vibrio* species sequences, we concluded that the genus *Vibrio sensu strictu* comprises at least 16 species. The two-dimensional evolutionary tree, constructed using the computer program Kitsch, based on the method of Fitch and Margoliash (1967), is depicted in figure 1. This representation is valuable in the inferrence of common ancestries of bacterial lineages since it

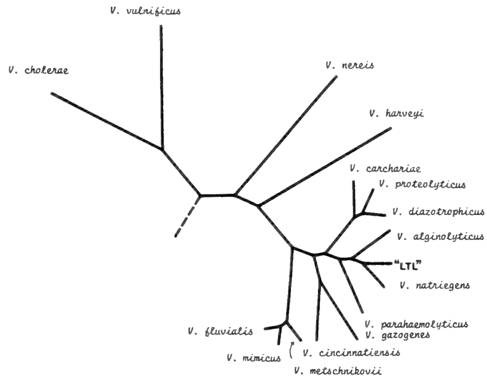

Fig. 1. Evolutionary tree, based on 5S rRNA sequence data, depicting phylogenetic relationships among species of the genus *Vibrio sensu strictu* (see text for discussion). Isolate "LTL" is an unnamed psychrophilic *Vibrio* species.

provides an estimation of branching order. Nevertheless, it suffers from its limitation to two dimensions. On the other hand, a hyperspace plot in five dimensions (figure 2), using a principal coor-

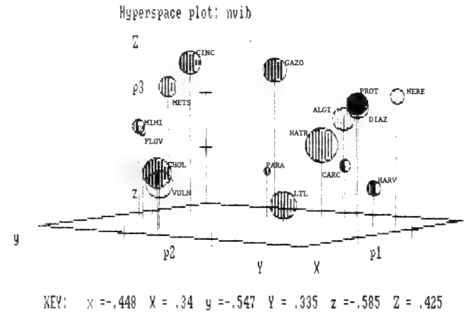

Fig. 2. Hyperspace plot in 5-dimensions depicting relationships among species of the genus *Vibrio sensu strictu*. Data were the same as used for the construction of the evolutionary tree in Figure 1 (see text for discussion). Key: principal coordinate (pc) 1 = X, pc 2 = Y, pc 3 = Z, pc 4 = volume, pc 5 = shading. Strains: ALGI = *V. alginolyticus*, CARC = *V. carchariae*, CHOL = *V. cholerae*, CINC = *V. cincinnatiensis*, DIAZ = *V. diazotrophicus*, FLUV = *V. fluvialis*,GAZO = *V. gazogenes*, HARV = *V. harveyi*, LTL = strain LTL, METS = *V. metschinkovii*, MIMI = *V. mimicus*, NATR = *V. natriegens*, NERE = *V. nereis*, PARA = *V. parahaemolyticus*, PROT = *V. proteolyticus*, VULN = *V. vulnificus*. Principal components were calculated and plotted using the computer program PCA (available on request from the author).

dinates analysis approach, adds substantially greater detail to the interrelationships among *Vibrio* species, although it lacks information on branching and common ancestry.

Conclusions

Through the use of modern nucleic acid purification and sequencing methods, computer-supported comparative analysis of ribosomal RNA sequences, algorithms for the construction of evolutionary trees, and computer-generated graphics for the analysis of the complex interrelationships among closely related bacterial species, it has become possible to construct a genuine phylogenetic taxonomy of the prokaryotes.

As a result of a three year study involving the determination, evaluation, and comparative analysis of the sequences of the 5S rRNAs purified from species of the eubacterial family Vibrionaceae, that family has undergone substantial taxonomic revision (MacDonell and Colwell, 1985; Colwell, MacDonell and DeLey, 1986). As a consequence, it has become the first major prokaryotic group to have a phylogenetically-defined taxonomy.

Using these and other techniques currently under development in our laboratory, this study is being extended to include other eubacterial families, including the Enterobacteriaceae and Pseudomonadaceae.

Acknowledgments

Support for this research was provided, in part, by National Science Foundation Grant BSR-82-08418, Office of Naval Research Grant N000-14-81-K0638, University of Maryland Sea Grant College, and The University of Maryland Center of Maryland Biotechnology.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, Pages 267–269, December 1986

STATISTICAL AND MATHEMATICAL MODELING OF ECOLOGICAL SYSTEMS

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The mathematical and statistical modeling of ecological systems has been an extremely active research area over the past two decades. This period has seen a great increase in our appreciation of the ability of mathematical models to abstract, translate, quantify, and predict the dynamics of environmental communities. From simple mathematical models of exponential growth to extensive computer simulations of eons of evolution through natural selection, mathematical models have done much to extend our understanding of processes that are difficult if not impossible for humans to even observe, much less directly control.

The development of ecosystem models draws on many related disciplines, and problems in one area often lead to new researches and approaches in another. My own work has led me from stochastic ecological models, to time series analysis, to spatial statistics, all in an effort to model and quantify environmental concerns.

Long before the development of computers, mathematical modeling of the actions and interactions of environmental communities received considerable attention. Then as now one central component in models of the dynamics of communities was DIFFERENTIAL EQUATIONS. These equations describe the rates at which populations change size due to birth, deaths, predation, etc. The general qualitative and more specific quantitative behavior of these equations provide useful insights into the influences on the communities. For example, a classic predator and prey model due to Volterra predicts that a heavy dose of a general pesticide applied to pest insects (the prey) has an even greater adverse effect on the benefical insects who are their predators. Our earlier use of the pesticide DDT was a tragic example of this effect. See Roughgarden (1979) for a discussion of this model.

Unfortunately, real communities exhibit random fluctuations that complicate the models significantly. These fluctuations could be due to environmental randomness of available light, nutrients, etc. or to the demographic randomness of birth, death, predation rates. In a series of papers Jernigan and Tsokos (1979, 1980a, 1980b, 1980c) and Jernigan, Turner, and Tsokos (1980) investigated, both analytically and using computer models, the effects of these random actions on a model for primary nutrient production in an aquatic ecological system. The interactions of three components were investigated: the producers, phytoplankton; the consumers, zooplankton; and the standing stock chemical nutrients. Differential inequalities were used to examine the effects of demographic randomness through rates of nutrient uptake, release, predation, and death. A DIFFERENTIAL INEQUALITY describes relationships embodying the simple idea that if the size of one population starts below another, and its rate of increase is always less than the other, it will remain smaller for all time. With these methods it was possible to obtain bounds on and inter-relationships between the parameters that govern the rates of change so that we can guarantee that the ecosystem does not become extinct. These bounds helped to provide a sound theoretical basis for more intuitive approaches to the actions. Computer modeling of this ecosystem allowed us also to examine the effects of environmental randomness. For example, parameters that governed the grazing of the zooplankton on the phytoplankton were seen to be negatively correlated with the number of zooplankton. Here we see the Volterra principle at work again. The more the zooplankton grazed the more their numbers were decreased by the limited phytoplankton supply.

To be even more useful it was needed to tie the developed theory to real time dependent chemical and biological data collected on an aquatic ecosystem, Jernigan and Turner (1980). The statistical analysis of time dependent data known as TIME SERIES ANALYSIS has found use in a variety of fields. A widespread type of time series analysis is based on the study of a descriptively rich class of models known as AUTOREGRESSIVE and MOVING AVERAGE models. The autoregressive models attempt to explain the present measurement as a sum of multiples of previous measurements plus a random shock. The moving average models evaluate the present measurement by averaging a neighboring sequence of random shocks. These models are often mixed to incorporate even more involved time dependencies.

The problem in much of time series analysis is the identification of these models from observed data. These observed data, being influenced by random, uncontrollable shocks, can mask the true underlying model that produced them. The identification process often lies on the border of art and science. The development of objective tools for such identification is a challenging task.

The problem of identification involves defining the right statistic to measure and consistently specify the type of model that generated a given set of data. Traditional methods have constructed a taxonomy of forms based on how neighboring measurements are correlated with each other, that is, are they usually above their mean together or on opposite sides of their means. These methods attempt to identify the underlying model by matching descriptions of the observed data with a catalog of ARMA behaviors. These methods work well, until we encounter mixed models.

A new technique for the identification of these mixed models calculates and combines correlations in various tabular forms, called R and S arrays, by Gray, Kelley, and McIntire (1978). In the absence of sample variability, R and S arrays can uniquely specify the underlying model. Unfortunately, no indication of how sample variability effects these arrays was given. Nguyen and Jernigan (1983) developed large sample formulas for the variance of these identification arrays resulting in a procedure to recognize even the mixed models with greater confidence.

Unfortunately, more difficulties remain. A new formulation of dependence called ASYMMETRIC TIME SERIES by Wecker (1981) allows the random shocks to influence the observed data in different ways depending on the size of the shock. For example, if the last shock to the system was positive it might have a totally different effect than if it was negative. What is remarkable is that one such model with a definite purposeful construction cannot be distinguished from totally random noise! The development of computational methods to resolve this ambiguity have been developed by Welsh and Jernigan (1983) and Marticello and Jernigan (1984). A new statistic based on the averages of powers of adjacent measurements has proved most useful in identifying these asymmetric models. Asymptotic theory shows that this statistic follows the well known normal distribution for large samples.

The theory and basic methods of time series analysis can be extended to cover more general situations. The analysis of SPATIAL DEPENDENCIES is one such example. Such problems are of great interest, for example, in the mapping of pollutant flow out of toxic waste sites. The complication here is that dependencies can be in several directions at once, not simply only on past data, as in time series. A spatial interpolation scheme called KRIGING, after D. G. Krige a mining engineer, uses the same basic techniques for estimation and prediction spatially, that time series analysis uses temporally. Much of the theory and practice of kriging have been with large data sets, and asymptotic results are common. In Jernigan (1986) some approaches to studying this estimation scheme in small samples are considered. This approach addresses the important issue of efficient estimation of spatial relationships when sample sizes are restricted by resources.

These are just a few of the problems that have arisen through the examination of environmental concerns. One of the great strengths of mathematics is the diversity of its applications. For most people, this is the primary reason for studying mathematics. Not only have applied problems in all fields been helped by mathematics, but any application serves to extend and enrich mathematics itself.

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Journal of the Washington Academy of Sciences,
Volume 76, Number 4, December 1986

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Required by 39 U.S.C. 3685)

1A. TITLE OF PUBLICATION	1B. PUBLICATION NO.	2. DATE OF FILING
Journal of the Washington Academy of Sciences		7/1/86

3. FREQUENCY OF ISSUE	3A. NO. OF ISSUES PUBLISHED ANNUALLY	3B. ANNUAL SUBSCRIPTION PRICE
Quarterly	4	$19. domestic; $22. overseas.

4. COMPLETE MAILING ADDRESS OF KNOWN OFFICE OF PUBLICATION *(Street, City, County, State and ZIP+4 Code) (Not printers)*

1101 N. Highland Street, Arlington, VA 22201

5. COMPLETE MAILING ADDRESS OF THE HEADQUARTERS OF GENERAL BUSINESS OFFICES OF THE PUBLISHER *(Not printer)*

1101 N. Highland Street, Arlington, VA 22201

6. FULL NAMES AND COMPLETE MAILING ADDRESS OF PUBLISHER, EDITOR, AND MANAGING EDITOR *(This item MUST NOT be blank)*

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