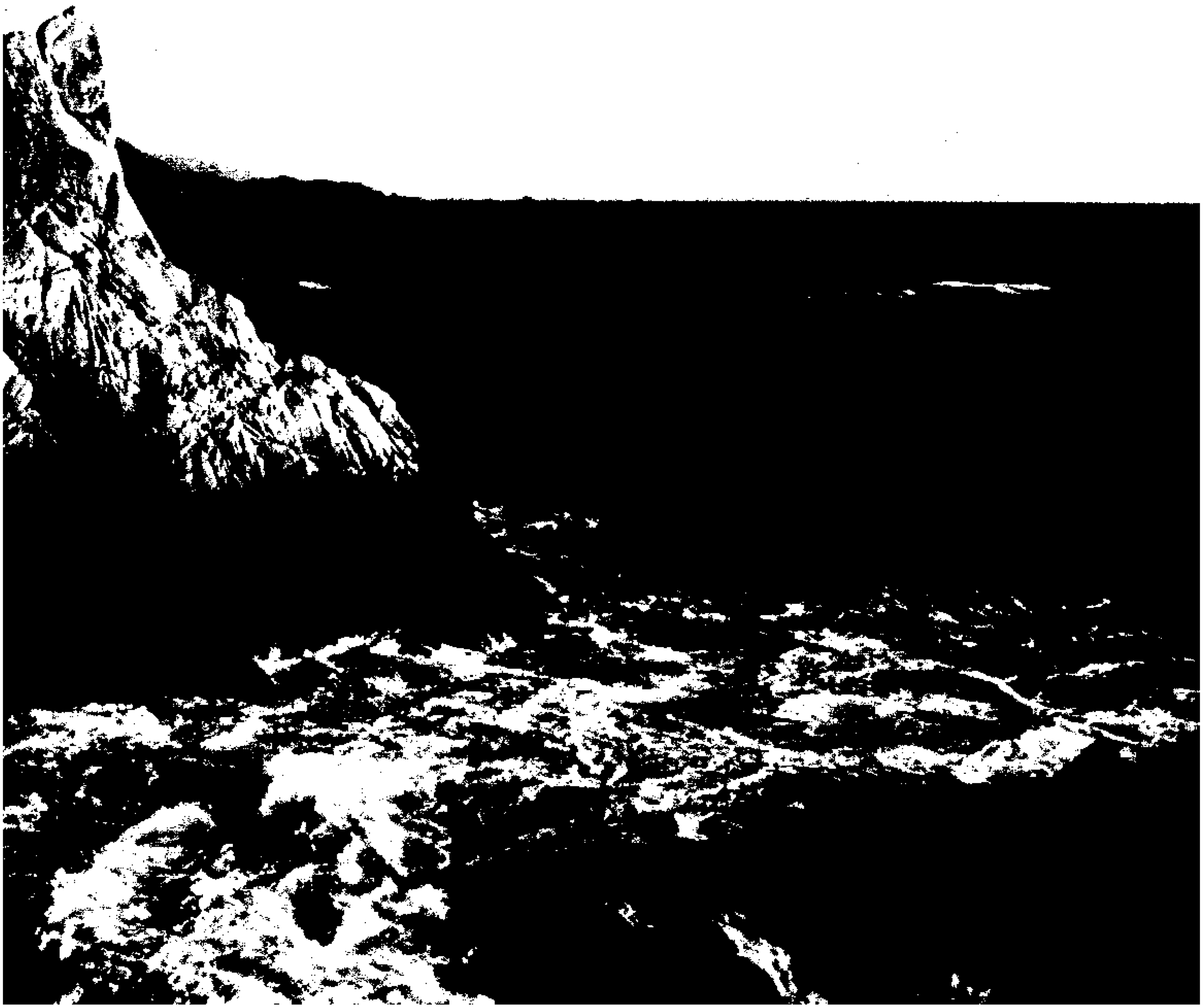
THE NATIONAL SEA GRANT NETWORK

Oceans of Opportunity



A product of the 89th Congress, the National Sea Grant College Program was conceived as a unique plan to develop and wisely use our nation's ocean and Great Lakes resources. It was created in the belief that the nation does not stop at the sea, that oceans of opportunity exist beyond the shoreline. The National Sea Grant Act of 1966 thus provided for the development of the nation's marine resources through a partnership between the federal government and educational institutions, much as the century-old Land Grant Act had provided for the development of the land.

Since its conception, the Sea Grant network has grown to encompass more than 300 universities and other marine organizations that work within a core of 29 Sea Grant colleges and institutions. The Office of Sea Grant, within the Department of Commerce's National Oceanic and Atmospheric Administration, provides national direction, leadership and coordination for the individual programs. It particularly encourages broad interdisciplinary cooperation among researchers to solve national and regional problems.

Under the program, institutions submit to the Office of Sea Grant proposals to conduct research, education and training, and technology transfer projects related to the marine sciences. Following a thorough review, including a site visit by a team of experts, a grant may be approved. By law, two-thirds of the funds for a project come from federal appropriations. The remaining one-third must come from non-federal sources.

The National Sea Grant College Program is the first federal program mandated to support activity across the full spectrum of the marine sciences. It has undertaken research projects on issues as diverse as coastal protection, estuarine health, fisheries development, and water quality. But the true genius of the Sea Grant concept is its ability to attack the traditional barriers between discovery and application through the technology transfer efforts of advisory/extension services projects.

Sea Grant, now in its third decade, will continue to address its goals to develop and wisely use our nation's ocean and Great Lakes resources in the belief they are central to our and the global community's health and prosperity. There are, indeed, oceans of opportunities for Sea Grant to pursue!

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A publication of the National Sea Grant Network, April 1989. *Victor Omelczenko*, editor, and *Susan Borda*, editorial assistant, National Sea Grant Office; *Amy Broussard*, design, and *Pat Lowry*, cover photograph, Texas Sea Grant College Program; *Charlotte Ingram*, insignia design, Georgia Sea Grant College Program; *Texas Sea Grant College Program*, production.

NATIONAL
SEA GRANT
COLLEGE
PROGRAM

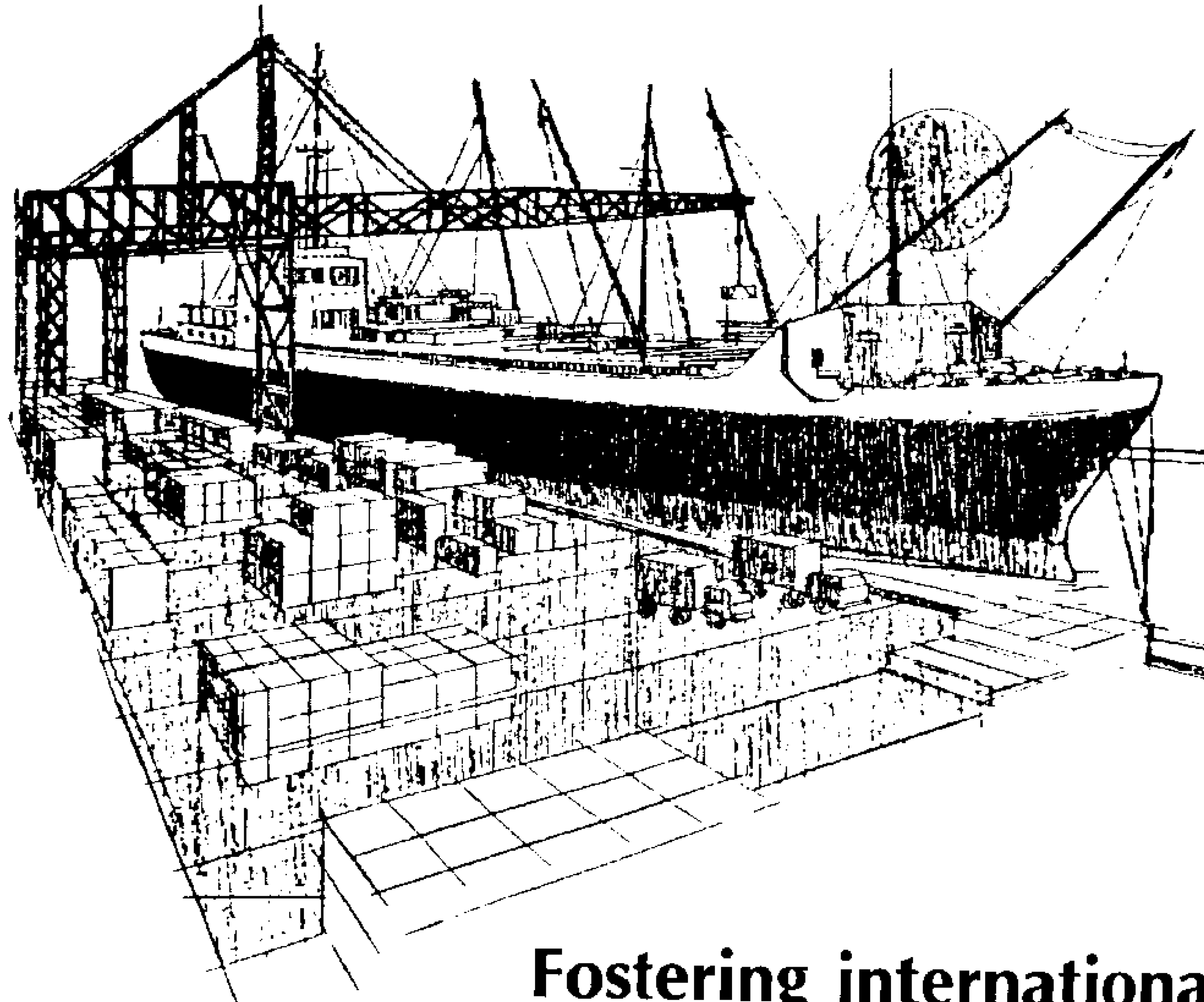
NOAA

The National Oceanic and Atmospheric Administration is a composite of its missions. Some of these missions are shared by the National Sea Grant College Program while others, such as marine biotechnology and education, are unique to Sea Grant. During the past decade, some of the shared mission responsibilities have gravitated to Sea Grant as the dominant, if not the sole, vehicle for fulfillment. These include aquaculture, seafood technology, shoreline processes, and research in the social sciences (economics, anthropology, law and policy, etc.).

Sea Grant is comprehensive in its approach to problem solving and disaggregated in its management style, utilizing more than 300 academic institutions through a network of 29 state and regional brokers. These factors that are at once the key to Sea Grant's success also serve to confuse the casual onlooker who is usually exposed only to individual parts rather than to the multidisciplinary national network as a whole.

It is the purpose of this document to demonstrate that the Sea Grant mechanism has the capability to recognize marine-related problems and opportunities, and to address them through national programs executed in a comprehensive, purposeful manner. The document does not address Sea Grant's other role, the ongoing conduct of basic research needed for the future across a broad front of marine economic development. That is a topic for another time.

Ned A. Ostenso
Director



Fostering international trade competitiveness

International trade competitiveness and national economic well-being are inextricably linked. Competitiveness means the degree to which a nation can produce goods and services that meet the test of international markets, and, at the same time, raise the real standard of living of its citizens. Recently, the President's Commission on Industrial Competitiveness reached three key findings about the U.S. economy:

First, the nation's ability to compete has declined over the last 20 years.

Second, consequently, if our national goals for economic security and a rising standard of living are to be realized, the U.S. must reverse this trend.

Third, it is essential for all administrators and executives in both the public and private sectors to make decisions in light of their competitive consequences.

Role of science and technology

The entrepreneurial capacity of the National Sea Grant College Program has been used to keep the United States a world-class economic competitor. The historical record of Sea Grant, illustrated later in several examples, demonstrates that it is a commanding factor in the development and growth of the marine sector of the national economy.

The large and persistent U.S. international trade deficits of the 1980's brought attention to important questions about the nation's competitive marrow. First among these, putting aside the broader trade and macroeconomic policy issues, is how to spur innovation and restore the nation's industrial productivity growth.

Experts differ about the solution. However, a reasonable consensus exists that U.S. economic competitiveness will depend more on the performance of science than it has in the past. There can be little doubt, then, that the U.S. must strengthen the capacity of our nation's research universities, which, since World War II, have been the prime engine of scientific discovery. Strong university research programs are critical, not only to explore promising scientific research areas but also to train the needed scientists and engineers.

At the same time, scientific discoveries alone are not adequate to sustain the nation's standard of living. America cannot play the role of laboratory for the world, producing the scientific ideas while other nations make the products. Clearly, the competitive ability to produce commercial products that embody scientific ideas is the basis for a nation's trade advantage.

Sea Grant's role in international competitiveness

The National Sea Grant College Program, through its national research programs and technology transfer network, is well-adapted to the foreign trade challenge, receiving high marks as an effective industry competitiveness program. Sea Grant is set up to raise marine industry productivity, its approach distinguished by the deliberate setting of a development-oriented research agenda and by the attention given to transforming scientific results into commercial use.

Two insights about competitiveness and the innovation process guide Sea Grant's investment:

First, competitiveness depends not only on the discovery of scientific knowledge, but also on the speed with which this knowledge is used in commercial application.

The new reality of international markets is the quickened timetable of competition. The period available for industry to move successfully from scientific knowledge to commercial products is greatly reduced, more so than ever before. The Sea Grant network, recognizing the critically short time span industry faces, sets goals explicitly designed to press rapidly from scientific discovery to end-use industry application. First, from the outset, Sea Grant gears its national science agenda toward opening up new science-based opportunities for industry; then, second, it steadfastly commits to rapidly diffusing resulting technological innovations throughout an industry.

To work expeditiously within industry's market-imposed time limits, Sea Grant commits a balanced investment across the whole of the knowledge continuum, from discovery to use. This broad focus has not undermined the quality of science, as some pure advocates of disciplinary science would suggest. In fact, Sea Grant has demonstrated that its development-oriented research programs, often involving several disciplines, contribute no less rigorously to fundamental and basic scientific knowledge. But Sea Grant doesn't stop there. Its strength and intellectual vitality come from a science management ethic that, unlike other public research programs, also mandates attention to the process by which knowledge becomes embodied in commercial applications.

Second, science-based innovations are a key element in the competitiveness struggle, but are not enough to assure commercial advantage. A spectrum of features on the competitiveness plane called the "knowledge infrastructure" is also essential.

Economists studying national economic competitiveness can point to a list of critical determinants. The most important of these includes science-based technological innovation. But equally important is a nation's "knowledge infrastructure," the requisite conditions that enable new scientific ideas and technologies to diffuse widely and be quickly adopted by industry. The rate of industry adoption is not necessarily based exclusively on the merits of the innovation. If the infrastructure conditions are not present, newly discovered knowledge will be inefficiently captured by the commercial sector, reducing productivity and diminishing competitiveness in international markets.

The knowledge infrastructure touches across the broad social fabric of a nation's institutions, its natural endowments, and its investment in human and physical capital. It depends on progress in the functioning of socioeconomic and legal institutions, increases in human capability, enhancements to the stock and quality of natural resources, and the growth in physical assets that embody technological change. Investment in scientific research is likely to have a far lower economic return if these innovation threshold factors are ignored. Taken together, they make clear the necessary contours for rapid industry adoption of science-based innovations. Increasing national competitiveness, however, is not simply a matter of a hit or miss investment in them. Rather, systematic attention to all first-order competitiveness factors is necessary. Resolute assent to this ethic by Sea Grant is responsible for the high commercial adoption rate of its scientific discoveries.

Sea Grant invests both in producing knowledge and in moving scientific ideas along the path to marketable products. This latter aspect, the deliberate effort to improve the often sluggish process by which industry embraces scientific advances, makes Sea Grant different from other national research programs. The development of a strongly competitive marine sector, from Sea Grant's perspective, is a search for the appropriate investment across all elements of the innovation process. Programs of social science, legal, and policy research aid institutions to change in ways that promote innovation. Improvements in human capital are attained through graduate education and provision of life-long learning forums. What's more, Sea Grant adds to the natural resources available to marine industries through its environmental research program. And finally, it influences the pace of capital investment through technology transfer programs.

Sea Grant's contribution to marine sector competitiveness

The persuasiveness and the appeal of Sea Grant as a model industrial competitiveness program come from the high dividends realized since its inception. Sea Grant's history is a record of recognizing early on the pivotal opportunities and issues facing the marine industry, engaging the top scientific talent available, and propelling research results quickly from the lab or field into practical use. Four examples — taken from Sea Grant's marine chemistry, ocean technology, pollution research, and aquaculture — will be used to illustrate the point.

Marine Natural Products

Sea Grant's national program in marine chemistry has discovered scores of novel substances with broad potential commercial application in medicine, agriculture, and pollution control. Along another national research track, Sea Grant has directed a total-utilization program aimed at the complete recovery of protein and the development of marketable products from seafood processing wastes. These paths eventually converged in a research program focused on the marine polymer chitin and its derivative chitosan, made from shrimp and crab exoskeletons.

The program goal was to probe chitosan's properties and find commercial ways to use its unique characteristics. Full-scale testing of chitosan's properties in a wide variety of applications, however, depended on making sufficient quantities of the material available to scientists from many disciplines. In an agreement with the private sector, Sea Grant supplied research quantities of this material to any scientist doing fundamental research on chitosan's properties and uses.

The Sea Grant strategy paid off in many valuable contributions to fundamental polymer science. Additionally, a continual stream of new applications for chitosan are being found in medicine, water quality, and food processing. Many patents won by Sea Grant scientists are now licensed by firms in various industries. Even though the commercialization of this technology is just beginning, a recent forecast placed the near-term potential U.S. market alone in excess of $300 million in annual sales. Sea Grant's chitosan research program certainly produced a true innovation in that it is notably changing business behavior. As more marketable products come on line, shellfish wastes certainly will go from being a disposal problem for seafood processors to becoming a primary industrial commodity with a high value-added manufacturing potential.

Perhaps the most striking virtue of Sea Grant's long-term research effort can be seen in the recent discoveries of chitosan's antifungal properties. Chitosan is a natural, though minor, component of the cell wall of many soil fungi that are harmful to agricultural plants. However, the dormant form of the organism in the soil contains large accumulations of chitosan. Sea Grant scientists posited that an infusion of chitosan into the fungus may bring on its dormant phase, thereby making it harmless to plants. They developed an inexpensive chitosan treatment for wheat seed that protects the crop against soil fungus. Five-year field trials indicate a 10 to 20 percent higher crop yield and a higher protein content in comparison to the untreated seed. Research is continuing to investigate chitosan's effects on plants at the molecular level and will undoubtedly result in further discoveries that will prove useful in promoting disease resistance in many commercial crops. It is also likely to be among the largest returns to Sea Grant's chitosan research investment.

Ocean Acoustics

The term "remote sensing" is generally associated with satellite observations. However, in its broader sense, it refers to the collection of data from a distance, usually by automated means. Satellite observations have limited utility for assessing fisheries because of the inability of light to penetrate water. In contrast, sound penetrates water well. This property has been well recognized in navigation and undersea warfare. Sea Grant began a long-term research program in the late 1960's to link advances in electronics technology to a fundamental understanding of the acoustic scattering properties of fish stocks.

Ocean acoustics studies pioneered by Sea Grant—combining the talents of biologists, engineers, and physicists—provided an entirely new technology for conducting living marine resource research and assessments. Remote sensing of stock abundance and fish behavior by hydroacoustic systems is rapidly proving to be a sophisticated tool of fisheries science. Fishery managers trained by Sea Grant are bringing these new techniques to their agencies, markedly increasing their rate of adoption.

The hydroacoustics innovation improved the precision of resource survey information, making it possible to increase substantially the yield from fisheries to the benefit of the commercial and recreational industries. What's more, it ushered in the birth of a new domestic industry to manufacture high precision acoustic instruments needed for fishery research by university and management agency scientists. Today, this equipment is marketed throughout the United States and eight foreign countries.

Hazardous Waste

Hazardous wastes from industrial, agricultural and maritime sources have caused water quality and public health problems. Detoxification of wastes is costly and can result in a final product that is as toxic and difficult to deal with as the original waste products. Sea Grant research aimed at solving such problems in the marine environment often results in the development of new commercial technologies.

For example, Sea Grant started research to address treating a waste stream that contains multiple toxic effluents. The research goal was to develop, through the manipulation of various strains of bacteria, a biological mechanism for the cleanup of hazardous wastes in both saline and freshwater environments. The effort, carried out in laboratory microcosms of the natural environment, resulted in the discovery that colonies of microbes could be assembled that break down multiple toxic substances to harmless compounds.

The next step, testing these results under field conditions, made it desirable to join in a cooperative research effort with the private sector. Sea Grant initiated a joint venture with a domestic company that produces industrial diatomaceous earth. The firm wanted to test the commercial feasibility of using its product as a substrate for the Sea Grant produced toxicant-eating microbes to remove chlorinated organic compounds from wastes.

The field tests proved the concept and solidified the Sea Grant-initiated joint venture. Subsequent improvements resulted in many new commercial applications. Recently, the Environmental Protection Agency approved the procedure for cleaning up an abandoned waste disposal site, making it the first Superfund site in the nation to be detoxified using microbes. The technology is now licensed to several private corporations for use in cleanup of both hazardous and non-hazardous wastes sites all over the world. One firm, realizing a sharp business growth based on the Sea Grant microbe innovation, established branches in London and Tokyo to handle the market volume as interest steadily grows all across Europe and Japan.

Aquaculture

Sea Grant, for 20 years, has led the drive to develop a domestic marine aquaculture industry. The gap between U.S. seafood demand and domestic commercial fishing harvest has resulted in a $7 billion net-imports bill. Demand for fish outpaces the growth rate of that for any other protein source. Sea Grant works with good success to increase the production of the U.S. commercial fleet. But this route is limited, ultimately, by natural fish stock yields; many preferred species are already being fished at their maximum output. Sea Grant, grasping this fact early, made the decision to establish a marine aquaculture research program, seeing cultured products as offering the best chance to increase domestic supply. And fortunately for today's times, it also offers the best potential to reduce the seafood trade imbalance.

Sea Grant prepared a national aquaculture development blueprint to guide the program through the last decade. Today, we are in the successful industry takeoff stage for several commercial products, including shrimp, salmon, freshwater prawns, crawfish, and various crustacean and mollusk species.

A recent aquaculture innovation illustrates Sea Grant's ability to push both the discovery of knowledge and the needed infrastructure changes. Oysters are high priced and scarce during the summer season with beds normally closed to harvesting due to the drop in oyster meat quality. Sea Grant researchers genetically developed triploid Pacific oysters, a sterile species that does not expend energy producing gametes. This innovation makes possible a year-round oyster industry with good potential for export to the Asian markets.

An important infrastructure issue Sea Grant addressed was whether property rights protection could be given to organizations and firms that develop genetically-altered cultured fish species. The Supreme Court in 1980 granted General Electric a patent for a laboratory-produced strain of bacteria, but did not extend this

(continued on page 44)

Exploring the new realm of

Biotechnology, which encompasses a wide variety of ways to use plants, animals and microorganisms in providing goods and services, is enormously important to many commercial and public activities. For example, just the biotechnological production of antibiotics by traditional methods contributes more than $8 billion annually to the U.S. economy; these antibiotics are invaluable in medical practice. Traditional biotechnology based on use of terrestrial organisms produces other kinds of products and commodities for commerce, among them cheese, alcohol, and organic acids. Furthermore, the use of microorganisms in treating sewage and purifying water is essential to public waterworks.

Modern biotechnology, based primarily on the application of DNA technology to change the genetic complement of organisms, has stimulated much excitement and activity in scientific and commercial circles. These activities promise to add hundreds of millions of dollars to the economy by solving problems and providing new products and services, particularly in medicine and agriculture.

Recognizing the extraordinary diversity of marine organisms and their neglect as resources for use in traditional and modern biotechnology, the National Sea Grant College Program implemented a program of research that would explore the viability of marine plants, animals, and microorganisms as subjects for biotechnology. Parts of this program, such as that focusing on biochemistry, were initiated early in Sea Grant's history, others more recently. The program is still small, but already it has proven that interdisciplinary science can provide new approaches for developing marine resources — approaches conservatively predicted to contribute tens of millions of dollars to the economy.

The fundamental nature of Sea Grant's research in marine biotechnology and its direct contribution to advancing science have made it low risk as an academic activity. It trains students well-prepared for technical careers. The importance of the educational benefits are especially apparent at a time when the number of Americans receiving advanced degrees in science is declining. The added attribute of the program's relevance to problems and opportunities in development or use of marine resources gives the program its Sea Grant imprimatur.

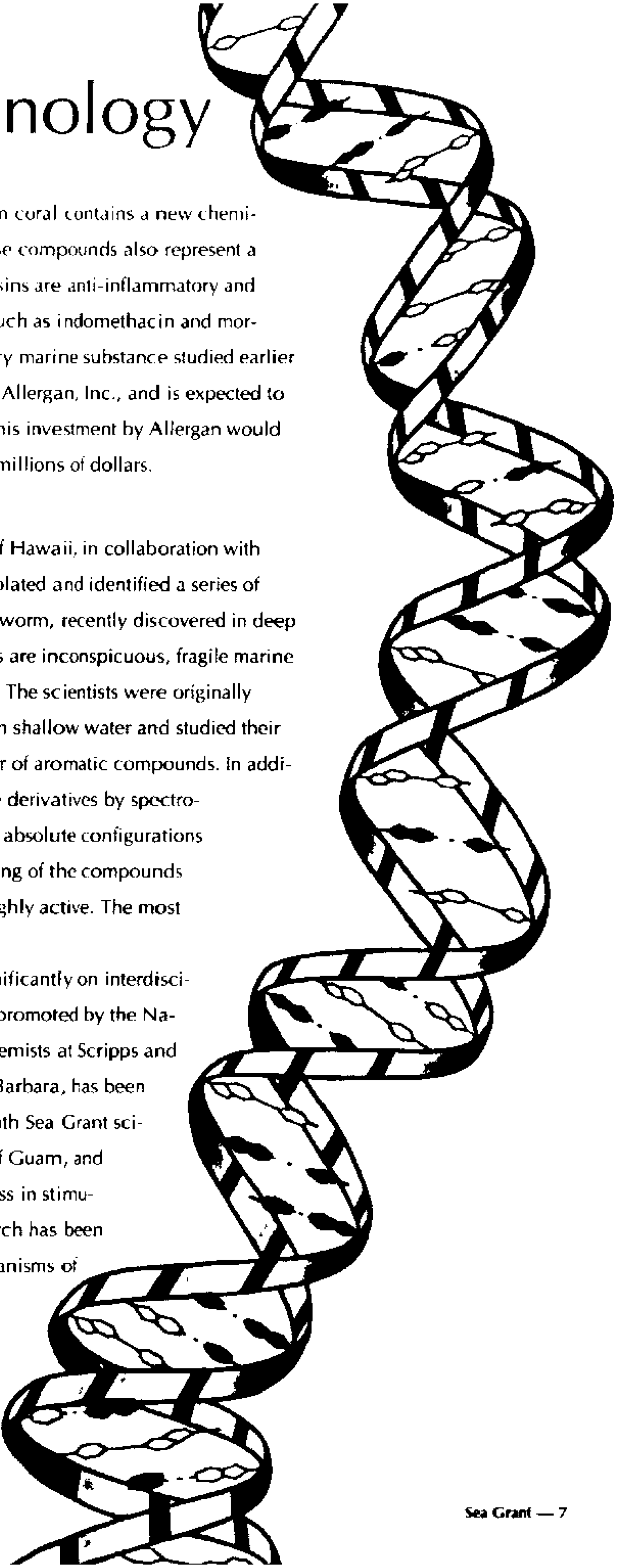
Biochemistry and pharmacology

Most drugs are natural substances from terrestrial plants or synthetic analogs of them. Nature will continue to serve as an important source of pharmaceuticals and an intellectual stimulus for scientists who develop synthetic drugs. However, the diminishing returns from continued screening of terrestrial organisms for new drugs, the slow progress in making synthetic substances with specific pharmacological properties, the lack of effective treatment for many diseases, and the continuing development of resistance to drugs by pathogenic organisms have stimulated Sea Grant's support of marine natural products chemistry and associated biological studies. The academic scientists conducting this research have defined the chemistry of many unusual new substances with potentially useful biological properties as the examples below show.

Anti-inflammatory Substances

At the Scripps Institution of Oceanography and the University of California, Santa Barbara, collaborating

marine biotechnology

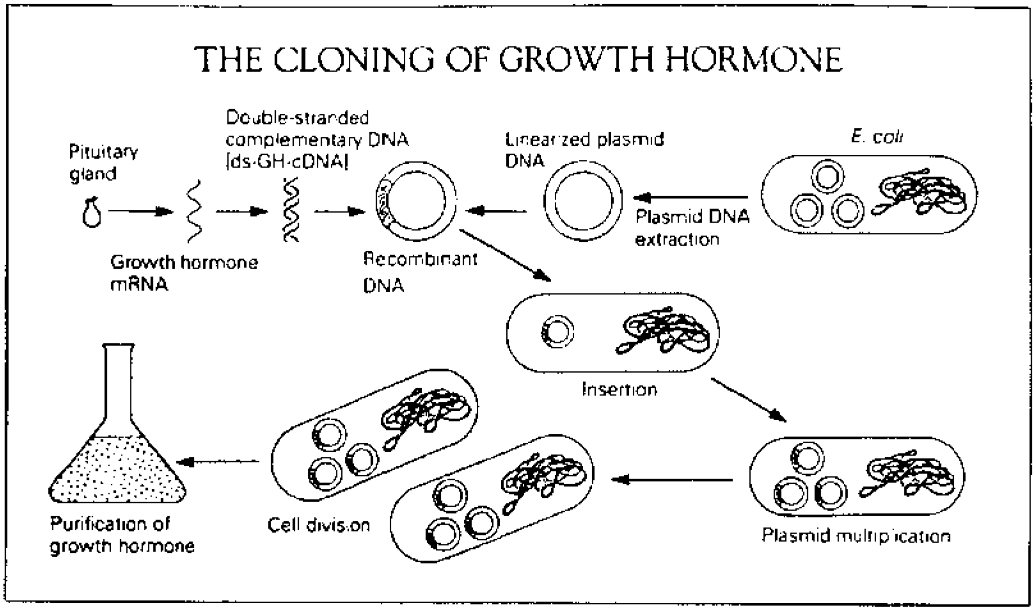


chemists and pharmacologists showed that a gorgonian coral contains a new chemical class of natural product, the pseudopterosins. These compounds also represent a new class of pharmacological agent. The pseudopterosins are anti-inflammatory and analgesic at levels greater than some common drugs such as indomethacin and morphine. Manoalide, another powerful anti-inflammatory marine substance studied earlier by the California group, now is under intense study at Allergan, Inc., and is expected to enter clinical trials within the next few months. If so, this investment by Allergan would indicate a market for manoalide at least in the tens of millions of dollars.

Antitumor agents from a marine worm

Scientists at Cornell University and the University of Hawaii, in collaboration with scientists at Japan's University of the Ryukyus, have isolated and identified a series of unprecedented constituents of a new species of acorn worm, recently discovered in deep underwater coves off the island of Maui. Acorn worms are inconspicuous, fragile marine invertebrates that live in sand, mud, or under pebbles. The scientists were originally intrigued by the iodoform-like odor of five species from shallow water and studied their chemistry. They determined the structures of a number of aromatic compounds. In addition, they determined the structures of six cyclohexene derivatives by spectroscopic methods. These structures were confirmed and absolute configurations were determined by x-ray crystallography. *In vitro* testing of the compounds against mouse P388 tumor cells showed them to be highly active. The most active was effective at 10 nanograms per milliliter.

Progress in this component of the program rests significantly on interdisciplinary cooperation and collaboration that have been promoted by the National Sea Grant Office. The collaboration between chemists at Scripps and pharmacologists at the University of California, Santa Barbara, has been mentioned. These pharmacologists also collaborate with Sea Grant scientists at the University of Oklahoma, the University of Guam, and the University of Hawaii. The pharmacologists' success in stimulating the interest of pharmaceutical firms in this research has been largely a result of their focus on looking for new mechanisms of physiological action and new points of reaction in biochemical pathways. Because the expense of bringing a new family of drugs to market is so great (up to $80 million or more), these firms are most interested in uniquely active compounds that might be the basis of



a new family of drugs. Much of the chemists' progress in structural studies of new compounds has depended on close collaboration with an x-ray crystallographer at Cornell University who also has Sea Grant support.

DNA technology

Genetic engineering or the application of DNA technology has the potential to enhance the exploitation of marine organisms in biotechnical processes. For example, it could be used to increase size, growth rate, or resistance to disease of marine plants and animals cultured for food or chemicals and to produce new vaccines and diagnostic reagents. It could also be used to improve metabolic capabilities of microorganisms used in processing wastes or cleaning effluents, or to increase the production of useful secondary metabolites by culturing microorganisms and cells of higher organisms. However, support for only a few Sea Grant projects focusing on applying DNA technology to marine species and problems has been possible, but results of this investment look promising too.

Transgenic Fish

Advancements in molecular genetics and gene transfer technology offer the means to introduce additional genetic variation within a species. This can result in production of species with improved traits for economic development — especially in aquaculture. To develop this technology for finfish, Sea Grant researchers at the Johns Hopkins University have used protein chemistry and genetic engineering to manipulate the genes in striped bass and white perch, and have devised an egg-holding microscope for micro-injection of genetic material into fish eggs. Recent results indicate that they will be able to produce transgenic fish.

To obtain good expression of a transferred gene, it must be spliced to a strong promoter. The mouse metallothionein (MT) gene has been widely used as a promoter because MT is a protein widely distributed in nature and its biosynthesis can be induced by heavy metals or corticosteriods. In order to gain a better understanding of the metallothioneins of fish and the genes encoding for them, the researchers at Hopkins studied the striped bass and the white perch. They purified the MT proteins with simple biochemical procedures and prepared gene banks. They used these genomic libraries to screen for sequences homologous to mammalian MT. They introduced additional copies of MT genes by micro-injection of fish eggs with their new device that both holds the egg and positions it so that the needle enters in the region where foreign DNA can be incorporated. Using the same technique, they have introduced the human growth hormone gene into a fish and are working to optimize conditions for its expression in the form of faster or greater growth.

Fish Vaccines

The diagnosis and control of diseases of fish such as infectious pancreatic necrosis (IPN), infectious hematopoietic necrosis (IHN), and vibrosis are economically important. Several years ago, Sea Grant scientists at Oregon State University produced useful vaccines to vibrosis, a disease common to cultured salmon, through conventional heat inactivation of the causative bacterium. Genetic engineering now promises to provide more specific and effective vaccines. For example, scientists at the Oregon Health Sciences Center cloned the gene for the outer membrane protein of *Vibrio anguillarum*, a major pathogen of fish. Other researchers have cloned the IHN virus for the same purpose.

Toxin assays

The unpredictable occurrence of ciguatoxin in tropical finfish can make eating seafood hazardous, so researchers at the University of Hawaii developed a rapid assay for detecting the neurotoxin. Their assay is based on the use of monoclonal antibodies to the toxin that comes from a dinoflagellate in the food chain. The assay may allow the detection of unsafe fish while still at dockside and, thus, increase both consumer safety and the use of tropical fish as food. Other dinoflagellates, microalgae that are ubiquitous in marine waters, also produce toxins and cause many filter-feeding mollusks to become toxic and unsafe as food sources. Thus, advancements in detection and control of toxicity and disease in fish and shellfish are important. The issue of disease is also important in aquaculture because production is projected to rise from the current 535 million pounds annually to 1,000 million pounds by the year 2000.

Biochemical and chemical engineering

Design and experimentation with systems and procedures for producing marine organisms or their cells and recovering their products for commerce would fall into the broad category of biochemical and chemical engineering. For example, bioreactors could be designed to recover pharmacological agents, enzymes, vitamins, pigments or oils from cultures of marine bacteria, algae or cells of higher organisms, but little research of this kind has been undertaken yet. Also included would be investigations of the use of biological materials in technology such as high temperature enzymatic reactions and biogeneration of energy.

Production from marine sources of feedstocks and primary chemicals is also a long-range goal and one that is even more dependent on economic factors than the production of specialty chemicals which can be sold at high prices. When the price of petroleum and its chemical derivatives increases relative to chemicals from renewable resources, the importance of natural substances in commerce will be especially apparent. However, marine biota that represent a large potential source of useful chemicals have been studied very little.

Industrial chemicals detoxification

The presence of agricultural and industrial toxicants in aquatic environments is of concern from both ecological and health perspectives. Threats to both surface and groundwater supplies are posed by hazardous waste sites. Sea Grant scientists at Louisiana State University (LSU) have shown that microorganisms can be used in bioreactors to detoxify chemicals in industrial effluents or to decontaminate waste sites. They selected yeasts and bacteria that could be immobilized on solid support matrices and developed optimal conditions for their use in detoxifying chlorinated phenols, PCB's, and other toxicants such as wastes from industrial plants that produce herbicides. They achieved continuous removal of toxicants for periods of three months or longer with residual levels of 100ppb or less. For solid waste sites, the LSU investigators developed mixtures of microbial species with broad catabolic abilities and defined optimal levels of application of the microbial mixtures to such sites.

LSU has licensed the Manville Service Corporation to commercialize its bioreactor technology. The university has also negotiated a contract with Environetics, Inc., to use the new technology for detoxifying solid waste disposal sites. Twelve new jobs have been created for testing these new systems; another six are to be added shortly. The market for application of this technology is estimated at $9 million per year within five years. This is the result of Sea Grant investment of $164,000, followed by state and private sector support of $435,000.

Microbiology and phycology

A wide range of research important to producing goods and services from the marine world falls in this relatively underdeveloped category. Some important themes that now need attention include: (1) fundamental processes in biofouling and bacterially-mediated corrosion, (2) biochemical processes in organisms from extreme environments, (3) use of marine polymers in control of disease in agriculture, and (4) development of food and feed plants tolerant of salty conditions. Other themes that have potential for contributing to commercial and technical advancements include biosensors and biological generation of power for underwater vehicles.

Control of biofouling and corrosion

Bacteria play an important role in the fouling of surfaces in marine ecosystems. Several investigations indicate that some invertebrates settle preferentially on surface films composed of microorganisms, but the biochemical processes in their settlement are only beginning to emerge. Researchers at Harvard University have proposed a model for settlement and metamorphosis of invertebrate larvae that involves lectins, which are proteins and glycoproteins that bind very selectively to certain units of sugar. They have developed evidence that a lectin on the surface of the larvae "recognizes" and binds to sugar units in exopolymers of marine bacteria. Researchers at the University of California have shown that another class of substance also is involved in settlement of larvae. Specific natural products, including gamma aminobutyric acid (GABA), a normal component of a crustose red alga, cause settlement and metamorphosis of abalone larvae. At the University of Maryland, researchers found that another amino acid, DOPA, induces such behavior in oyster larvae. Because all invertebrates that foul submerged surfaces in marine environments are recruited as larvae from the plankton, knowledge of the biochemical inducer systems can be applied to the development of species-specific inhibitors. It may be possible to use analogs and derivatives of these biochemical signal molecules to tie up the chemoreceptor sites and prevent settlement and metamorphosis of larvae. Thus, the development of such biological control would obviate the use of toxic antifoulant paints which are associated with a variety of environmental and health hazards.

Disease resistance

The mechanisms through which plants recognize pathogens are poorly understood. A first step for establishing the molecular basis of disease resistance in plants may be to identify genes whose expression follows biochemical changes during infection. Researchers at Washington State University have found that the marine polymer chitosan can activate specific genes in plants that stop RNA synthesis in some fungal pathogens and, thereby, protect the plants. While stimulating disease resistance in plants, chitosan can induce gene activity and inhibit reproduction in an array of fungi such as those causing athlete's foot and Dutch Elm disease. Inexpensive treatment of wheat seeds with chitosan prior to planting provides seedlings protection from root-rotting pathogens and increases yields up to 20 percent. Preliminary evidence suggests chitosan also increases protein content of wheat seeds, a particularly important finding in highly managed agriculture such as that practiced in Europe. Washington State has patented some of the discoveries and licensed them to a commercial firm that anticipates rapid growth and a significant level of exports. The researchers believe their studies of disease resis-

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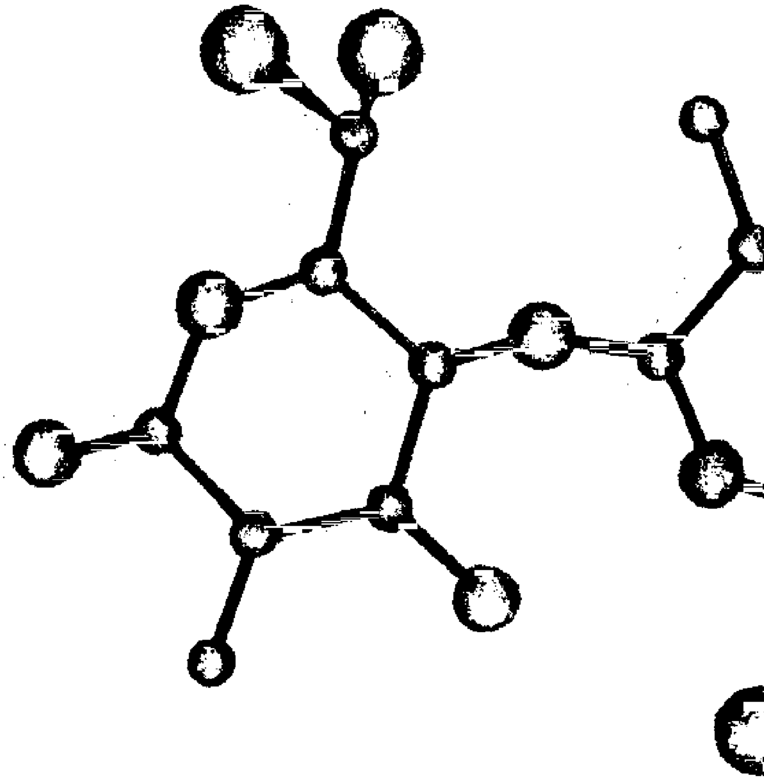
Discovering Marine



One focus of the National Sea Grant College Program has been the discovery of new organic substances of marine origin and the development of uses for them and other marine natural products. For example, in the early 1970's Sea Grant recognized that wastes from seafood processing were both a growing disposal problem and a potential source of raw material for by-product recovery. Sea Grant then supported the pilot-scale production of chitosan, which is a polymeric material derived from chitin, the major component of shrimp and crab shells. Samples of chitosan were distributed to any researcher requesting them, and the availability of this material spurred research in the United States. Sea Grant was early to commit to developing these products and continues to sponsor much of the ongoing basic research. This research has led to a variety of new commercial products. In 1987 **Bioprocessing Technology** forecast a $335 million annual market in the United States for chitin and its derivatives.

Sea Grant's research on natural products also has included the study of secondary metabolites of marine plants and animals. Secondary metabolites are natural organic substances having no obvious biochemical role in the functioning of an organism. Many are chemically exotic and exhibit biological activity, the ability to elicit a physiological response in a test organism. Because a majority of pharmaceutical substances have their origins in secondary metabolites of terrestrial plants and microorganisms, Sea Grant's managers in Washington D.C. saw the potential for developing drugs of marine origin and forged collaborations between chemical and biological scientists, especially pharmacologists. The resulting work in marine natural products demonstrates the relationship between research and advancement of technology and commerce.

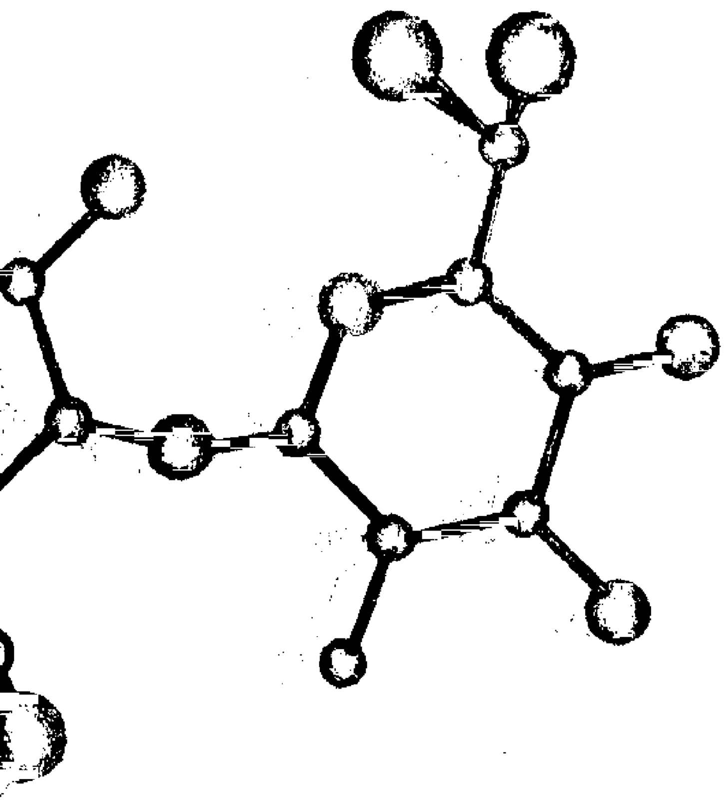
Pharmaceuticals

The high incidence of biological activity associated with secondary metabolites of marine organisms underscores the potential richness of the marine environment as a source of compounds for use in medicine. The emphasis in research to date has been on determining the chemical structures of the varied and exotic compounds isolated from marine organisms. The focus has been the obvious and easily collected members of coastal fauna and flora. In general, the biological function and pharmacological or medicinal properties of these substances have not been investigated. The primary efforts in this direction have been through the National Sea Grant College Program. Some of the new marine substances are evaluated in a few biological or pharmacological assays. This research has produced numerous promising leads, and some discoveries that are in the early stages of commercialization.

Manoalide is one of these new substances. Scientists at the University of Hawaii first isolated it from a Pacific sponge and then determined its structure. Coincidentally, a researcher at the Scripps Institute of Oceanography also isolated manoalide and related compounds from another specimen and submitted them for pharmacological evaluation. Then, researchers at the University of California at Santa Barbara documented manoalide's anti-inflammatory and analgesic properties. Its potency has been found to be greater than that of indomethacin, an anti-inflammatory standard of the pharmaceutical industry, but its site of action is different. While it is less potent than cortisone, manoalide exhibits a pharmacological spectrum different from that of steroids. Because it is not a steroid, manoalide is not expected to have the adverse side effects associated with steroids.

Manoalide's potential uses include treatment of rheumatoid arthritis, rheumatic carditis, autoimmune diseases, allergic diseases, bronchial asthma, and ocular and skin inflammatory diseases. It may be useful as adjuvant therapy associated with organ and tissue transplants and neurological disease such as multiple sclerosis. Because it ameliorates chemical irritation and it prevents the paralytic action of ß-bungarotoxin, another standard in pharmacological testing, manoalide may be useful in the treatment of venoms such as certain snake and insect bites. Since manoalide blocks induced inflam-

Natural Products



mation it could be useful in treating certain forms of allergic contact dermatitis like that from poison oak or poison ivy. Accordingly, researchers believe manoalide will make a significant advancement in the pharmaceutical arts. As a result of the academic research on manoalide and protection of the related intellectual property with patents, Allergan, Inc. a pharmaceutical firm, is pursuing development of it. If manoalide is introduced to the pharmacopoeia, it is likely to have a worldwide market in the tens or hundreds of millions of dollars annually.

Signal molecules

Research can effect progress in seemingly unrelated fields of inquiry. A good example comes from efforts to improve aquaculture by identifying biochemical signals affecting reproduction and development in mollusks. Extension and application of these findings are expected to advance technologies for sophisticated diagnosis and control of disorders of the central nervous system in humans.

Aquaculture is receiving increased commercial attention as a method for supplying seafood. Development of strategies for improved cultivation and ocean ranching of abalones, mussels, clams, and oysters requires control of biological processes that limit yield and efficiency of production. Thus, a fundamental understanding and control of processes such as reproduction, larval settlement and metamorphosis are needed.

Studies at the University of California at Santa Barbara have shown that reproduction in abalones and variety of other mollusks is controlled by hormones known as prostaglandins. Thus, spawning can be induced in reproductively competent males and females by adding prostaglandins to the seawater in which they are contained. However, because the use of expensive hormones for this purpose is impractical, an alternative approach was needed. Research showed that hydrogen peroxide (H_20_2) is a key substrate in controlling prostaglandin biosynthesis in mollusks. Because H_20_2 is an inexpensive chemical, the researchers developed methods for its use in inducing spawning.The addition of a small amount to tanks holding abalones causes immediate and copious release of eggs and sperms. This method is used now in research and commerce to synchronize reproduction in large numbers of mollusks and to obtain larvae.

Free swimming larvae of abalone hatch from fertilized eggs in about one day. Sustained entirely by nutrients in the yolk, they normally drift in the coastal waters for approximately one to three weeks without feeding. During this period they are highly susceptible to predators and microbial infection; therefore, rapid settling and metamorphosis are distinct advantages. Although the larvae become competent to settle and metamorphose to the juvenile stage soon after hatching, they must be induced to do so by biochemical signals present in appropriate habitats. Because the natural inducing biochemicals are present in very low concentration under the conditions of cultivation, improper settling and metamorphosis can result in heavy losses.

Sea Grant scientists also isolated substances in specific red algae that induce settling and developmental changes in abalone. Abalone commonly settle on these algae in nature. Analysis has shown an analog of ∂-aminobutyric acid (GABA) to be a major component. GABA, a common and readily available amino acid, also will induce settlement and metamorphosis. In fact, it is the most powerful of the inducers studied. When added in concentrations as low as one part per million, GABA induces quick settlement, metamorphosis, juvenile development, and growth in almost 100 percent of larvae with no observed mortality. This is the first example in which GABA, a principal neurotransmitter in the mammalian brain, was shown to induce metamorphic changes in an animal. Use of GABA not only results in greater yields of abalone at a lower cost, but also produces healthy juveniles that grow faster than juveniles obtained with traditional hatchery technology.

Almost 50 percent of the neurons in the human brain and the spinal cord are controlled by the neurotransmitter GABA.

Therefore, it is not surprising that a major proportion

Certain marine algae and bacteria have been shown to produce GABA-mimetic peptides

Marine Natural Products

of prescriptions for drugs in the United States is for agents that act as receptors for or at sites of uptake for GABA. Such drugs are prescribed for control of convulsion, sleep disorder, muscle dysfunction, and other nervous system functional disorders. Because of the distribution of a very large number of GABA neurons in the central nervous system and the low selectivity of the drugs currently in use, both diagnostic and therapeutic success with these drugs are quite limited. Therefore, enhanced specificity is needed to minimize the side effects inherent in the use of non-specific drugs.

Certain marine algae and bacteria have been shown to produce GABA-mimetic peptides, substances mimicking the action of GABA. These peptides bind strongly and selectively with GABA receptors from the mammalian brain. By means of specific structural changes, these peptides could provide unique opportunities for development of a new class of therapeutic agents for medical diagnosis and treatment of related disorders of the nervous system. Sea Grant scientists are currently working with medical researchers and several biotechnology companies to explore the potential of these GABA-mimetic peptides. They expect each of the GABA-mimetic peptides and their synthetic analogues to have unique effects on nervous function because of differences in binding site and strength. If so, it may be possible to greatly refine treatment of nervous disorders. This prospect is especially exciting because these new substances can pass the barrier between circulatory blood and the brain, a passage impossible for many current drugs.

Anti-scalant substances

At the University of South Alabama and Clemson University, collaborative Sea Grant studies on how oysters make their shells led to the finding that the protein which forms the matrix of oyster shell inhibits calcification, the crystallization of calcium carbonate ($CaCO_3$). This was surprising because $CaCO_3$ is the primary material of the shell, and the protein was expected to promote formation of $CaCO_3$. However, scientists recognized the relevance of their results to potential application in preventing both inorganic and biological calcification, processes which are of enormous cost to industry. For example, $CaCO_3$ deposits foul cooling towers, condensers, and boilers. In the United States, industry spends more than $100 million each year on synthetic inhibitors of calcification, some of which have deleterious environmental side-effects. In addition, fouling of ships and other man-made surfaces in the marine environment by calcifying organisms costs industry billions of dollars annually in direct losses, inefficiency, and control measures.

Control of $CaCO_3$ encrustation and growth of calcifying organisms on surfaces in marine environments has long been recognized as a potentially solvable problem. By preventing or slowing the occurrence of these "fouling" substances in organisms, the useful lifetime of surfaces such as hulls of ships and pilings of docks can be increased. In the case of hulls of ships, prevention of fouling also has the effect of allowing the ship to move more efficiently through the water.

Historically, the problem has been approached by impregnating or coating surfaces with compounds that interfere with the metabolism of fouling organisms. For example, the use of inhibitors of carbonic anhydrase, an enzyme often involved in calcification, has been suggested. Less specific metabolic inhibitors, such as the toxic organotin compounds, are widely used now in industry.

$CaCO_3$ crystals can grow without the aid of organisms in most natural waters and cause unwanted deposits. For example, scale builds up in many places in the sea as a result of spontaneous crystal growth because seawater is supersaturated with respect to $CaCO_3$. Inorganic scales of $CaCO_3$ are also often encountered as unwanted deposits in pipes and boilers where supersaturation becomes a problem due to evaporation. Certain organic substances such as ethylenediamine tetraacetate (EDTA) have been used to retard or inhibit the precipitation of $CaCO_3$ in supersaturated solutions although high concentrations are needed for these compounds to be effective. Inorganic hexametaphosphate in low concentration was found to retard scaling and led to the widespread use of phosphonates as scale inhibitors in municipal and industrial water systems, but the phosphate inhibitors aren't ideal either.

In recirculating cooling water systems, calcium carbonate is generally the predominant scalant. Calcium carbonate is especially worrisome in industrial processes because it shows

an inverse solubility with temperature; it is less soluble at higher temperatures. Thus, scaling occurs on critical heat-transfer surfaces, reduces efficiency of operation, increases frequency of required cleaning, and decreases the life of systems. Chemicals currently used industrially to retard scaling and biofouling are not ideally effective and their use is costly. Some of them are toxic and may damage the environment.

The collaborative team from South Alabama and Clemson also determined the conditions under which natural matrices can control crystallization of $CaCO_3$. They showed that synthetic analogues of these proteins also can inhibit crystallization and control $CaCO_3$ formation. They reported their results in the scientific literature and in patent disclosures. The research has led to collaboration between the researchers and industry and pointed the way for research on other applications of the observed phenomena. These potential applications may be useful in aquaculture and medicine, for example, in preventing hardening of soft-shell crabs and formation of dental plaque.

In 1988, investors in Chicago put up several million dollars to form the Cygnus Corporation which will produce and market nontoxic and biodegradable products for the water treatment industries. In addition, another industrial partner will work with the Sea Grant researchers to develop products for oral health care.

Agricultural enhancer

Research on the natural polymer chitosan, which can be derived from shrimp and crab shells, shows that it kills certain fungal pathogens of agricultural crops. It is thought to activate disease-resistance genes in plants and suppress gene function in certain fungi that infect plants. Sea Grant studies were conducted at Washington State University on the use of chitosan to treat wheat seeds and pea seedlings in order to expand agricultural yield. Results have appeared in numerous scientific papers, and the university has secured patents for agricultural applications. Bentech Corporation in Oregon bought rights to them and is marketing chitosan and chitosan-treated wheat seeds.

In colonial times and later, coastal farming was enhanced by plowing excesses of fishing into the earth. Dead fish and seaweeds return nutrients to the soil. Today excesses are in the form of wastes from processing fish and shellfish. A new use of marine largess in agriculture has more of the flavor of high tech than it does organic gardening. The Washington State scientist has taken crab-shell waste that has been powdered, extracted, and demineralized as his marine additive. He's looked at the effects of the resulting compound, chitosan, on plant growth and disease resistance at the whole-plant level and at the molecular level.

The scientist, a plant pathologist, then developed a treatment for seeds that protects wheat against damage by a soil fungus. In field trials in an eastern Washington area where fungal rot is common, crop yield was up to 20 percent higher than that from untreated seed. More recently, studies have shown that the seed treatment also increases the content of protein in wheat crops, a feature demanding premium prices and very important to efficiency in highly managed agriculture such as that practiced in Europe. And in an Oklahoma wheat-growing area where root rot seldom causes visible wheat damage, chitosan-treated wheat had more grain per head, giving a 10 percent increase in yield and indicating that its growth-enhancing effects are not due to suppression of fungus alone.

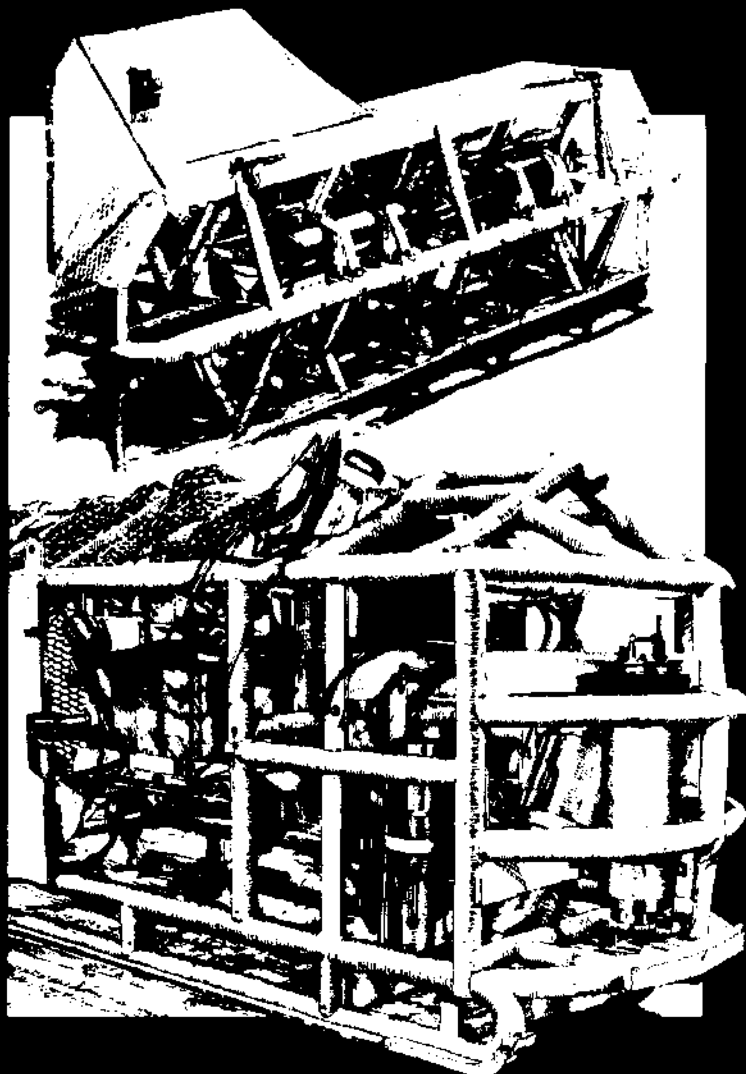
This inexpensive treatment for wheat seeds has virtues that go beyond its enhancement of yield

- It creates a new commercial use for shellfish wastes.
- It is providing a new product for international markets.
- Chitosan, a naturally occurring compound, does not have toxic effects often associated with synthetic chemicals.
- Determination of the fundamental mechanisms by which resistance to disease is induced may have generic application in and profound effects on fighting disease in plants and animals, including humans.

Conclusion

These examples of research advancements show their direct contribution to advancing fundamental science while providing the basis for new products and processes for medicine and industry. The list of useful discoveries and scientific advancements is expected to grow rapidly when greater investment can be made in studying other types of marine natural products and organisms.

— *David H. Attaway*



Developing unmanned underwater work vehicles

Our country's maritime heritage is testimony to the United States' early and long-standing global leadership in marine technology. American clipper ships set world speed records in Atlantic and Pacific trade. When they were surpassed by our steam, internal combustion, and then nuclear alternatives to sail power, these were also of our own design. In specialized areas, our icebreakers were the most innovative, drilling platforms the most diverse, submersibles the deepest, and supporting engineering technologies the most sophisticated.

Today, this is no longer true. The shipbuilding industry has almost disappeared in the U.S. despite the support of federal subsidies; there are no commercial ocean-going ships under construction in U.S. yards with the exception of small fishing vessels. Since World War II, we have built but three icebreakers. European countries have caught up to us in most oil-related offshore technologies, and surpass us in some areas, such as large concrete production platforms. Canada, Japan, Finland, and France have produced submersibles of greater capability than any existent in the United States. Across the board, foreign competitors exceed our production of sophisticated marine instrumentation.

What can Sea Grant do about this problem? Reversing our decline in offshore construction technologies and shipbuilding involves a number of complex market forces which this program could not hope to manipulate. Among the key elements necessary for international competitiveness, however, are: (1) sufficient supply of well-educated manpower, and (2) leadership in producing the innovations in science, engineering, and manufacturing processes that lead to the continual advancement of technology. The potential appears greatest in the application of emerging technologies such as robotics, artificial intelligence, and new sensor designs. Accordingly, Sea Grant has made the application of these technologies to undersea vehicles one of the foci for its limited resources. It is this effort that is reported here.

The U.S. Department of the Navy has recognized Sea Grant's capabilities and commitment to this area of research. Some of the effort that is reported was begun and continues with Navy sponsorship, for which Sea Grant is grateful.

Working in the oceans

Men working in the oceans, as in space, must have reliable life support systems because minor system failures can cause major catastrophes. Manned submersible vehicles have been developed for deep water studies and relatively simple work tasks, but they are costly to build and require expensive support ships. As we move into deeper waters for research and resource exploration, the hazards, the unknowns, and the expense increase dramatically.

In recent years it has become clear that special purpose unmanned submersible vehicles can augment or replace manned submersibles. The technology for unmanned submersibles is in its infancy, but further development is indispensable for any cost-effective program aimed at understanding the ocean environment and learning to wisely develop its vast resources.

Sea Grant research

Unmanned submersible vehicles fall into three classes: towed vehicles, which do not have power systems of their own; remotely operated vehicles (ROVs), which have motors and thrusters of their own, but receive electric power and electronic control signals from a stationary "mother" surface vessel; and autonomous vehicles (AVs), which operate completely independently of any surface vessel, utilizing pre-programmed instructions and self-contained power.

Sea Grant attention to unmanned submersibles began more than 10 years ago. In the early attempts to understand the limits of present technology, students at the Massachusetts Institute of Technology (MIT) and the University of New Hampshire (UNH), under faculty supervision, explored the possibilities of autonomous vehicle operation and built experimental vehicles. At approximately the same time, a towed vehicle with a camera system was developed in cooperation with NMFS at Mississippi State University (MSU). This vehicle was to be used for fisheries assessment and observation of the operation of fishing gear. Although none of these projects resulted in a successful operational vehicle, they did outline the problems, and therefore provided the basis for further program design.

Technology transfer

One of the first efforts to develop a regular dialogue between university researchers and industry professionals was the Marine Industry Collegium which was formed at MIT, but is not restricted in scope to this single campus. Meetings are held four or five times each year, at which industry presents its needs, and the commercial potential of current long-range research is explored. This activity has spawned various forms of continual informal interaction between industry and university. Because of the excellent working relationships which have developed, and the greatly increased level of knowledge, Sea Grant hosted a major international conference on underwater work vehicles in 1986. Participants included university researchers and representatives from all of the major U.S. manufacturing companies.

Towed vehicles

Towed vehicle research has paid off well, and relatively quickly. Three significant contributions by Sea Grant Programs include the development of a Towed Underwater Gear Observation System (TUGOS) at MIT with the cooperation and support of NMFS, a Semi-Automatic Magnetic Processing System (SAMP) developed by UNH with the cooperation and support of Navy, and a Remote Underwater Manipulator (RUM III) at the Scripps Institution of Oceanography.

TUGOS is only 36 inches long, 20 inches high, and has a wingspan of 42 inches. It weighs only 140 pounds and can be hand-launched from small vessels using a hand-tended tow cable. It can carry a variety of sensors, such as underwater video equipment, and is the first low-cost, easily-handled observation system of its kind. It is depth rated to 1,000 feet. This vehicle is being used by Sea Grant and NMFS for various fisheries research projects, and a Massachusetts-based company is already marketing its version of this design for commercial use.

Magnetometers have been used on towed vehicles to locate submerged objects. Previously, however, the signal from the sensor has been stored for analysis at a later date by an expert trained to recognize the peculiar pattern or "signature" characteristic of specific types of objects in that particular geographic location. SAMP essentially automates the data handling so that the same job of object identification can be done on board the survey vessel, virtually as it is collected.

RUM III is capable of working to depths of 20,000 feet. It can map the seafloor, take biological samples, and collect fairly heavy rocks or sediment cores. It consists of a main chassis, to which are attached TV booms and cameras, sonar instruments, thrusters, and a manipulator boom for coring, lifting samples, and placing instruments. The vehicle can crawl along the bottom for short distances on two smooth conveyer belt tracks. To move the vehicle significant distances, it is lifted off the bottom and towed by the cable from one position to another.

Remotely operated vehicles (ROVS)

With regard to remote operation, the attention of MIT researchers was directed to the specific problems associated with work systems having one or more manipulators. One approach, called supervisory control, assumes the remotely operated system is like a co-operative, but not very intelligent, as-

(continued on page 45)

Improving Trawler Efficiency

Vessel modification, fuel consumption, gear development

Today's fisherman is faced with many problems, including competition from imports, fully or overexploited stocks, and increasing fuel and operating costs. Early analysis by the National Sea Grant College Program of the technological aspects of this competitiveness and overall efficiency problem pinpointed three directions for likely improvement: (1) modifications to vessel design aimed at reducing drag resistance (vessel shape, propeller type); (2) improved engine design for better fuel efficiency; and (3) improvements in net design and usage.

In preliminary studies to define the problem carefully, the Mississippi Sea Grant Advisory Service outlined fuel consumption patterns by combining a questionnaire to fishermen, an onboard observer program, and data from three vessels instrumented to monitor fuel use during normal operation. A complementary study at the Department of Naval Architecture of the University of California added to this a review of manufacturer-supplied data and other literature to produce a listing of possible methods and equipment available to improve fuel efficiency and reduce costs. This included suggestions for reducing vessel speed, hull maintenance, bottom paints, improved propellers, and special nozzles for the propeller. Approximate costs and disadvantages were given along with an estimate of the possible savings.

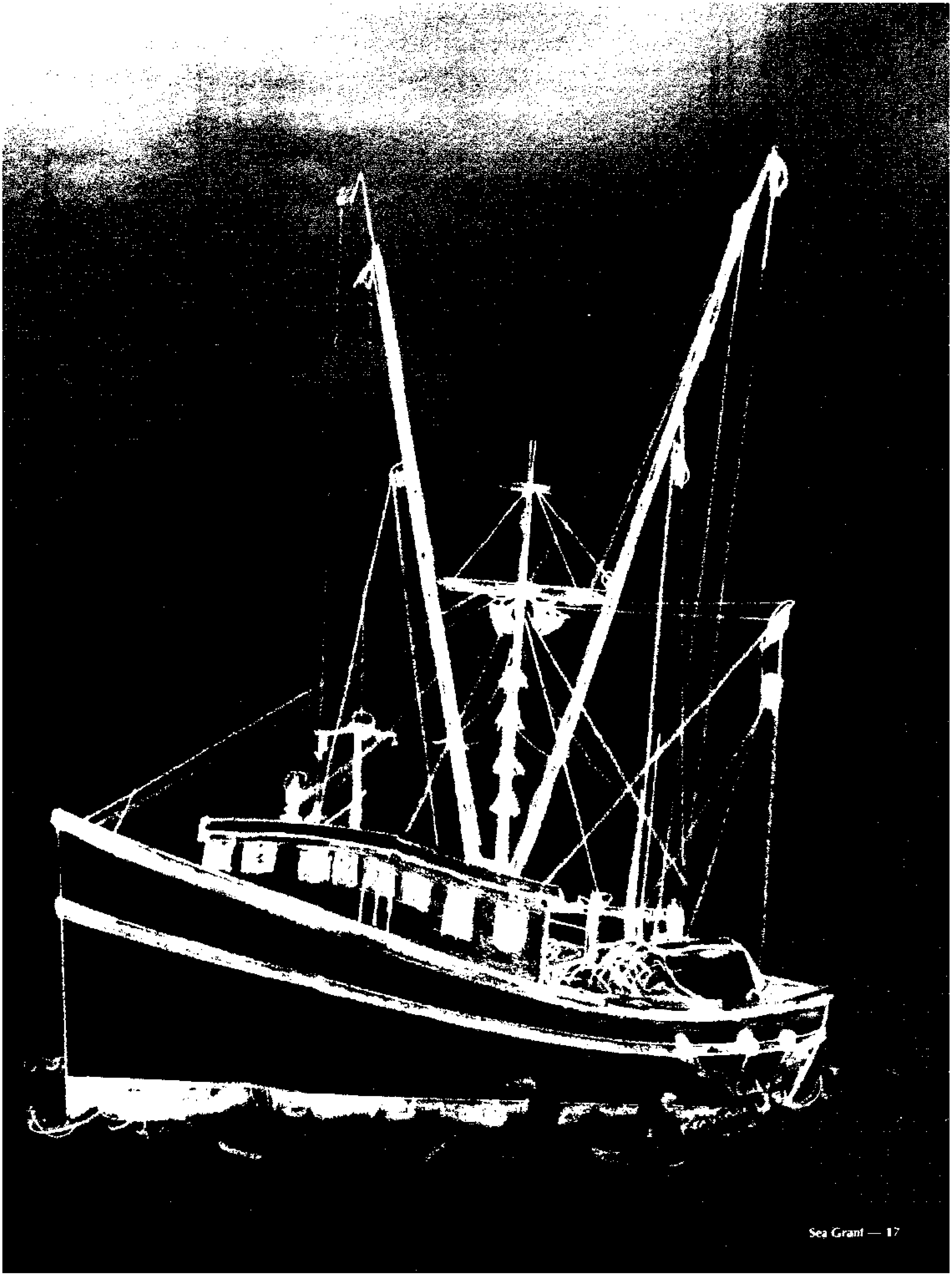
The information from these studies has been used by the various Sea Grant Marine Advisory (Extension) Services programs throughout the country to alert fishermen to the possibilities open to them. However, the variety of vessel sizes and shapes, engine types and power, and propellers produces virtually a different situation for each fisherman. The optimum choice and investment decision was seen to be a difficult one.

Matching hull, engine and propeller

A trawler must perform reasonably in two very different operating conditions, trawling and free running. A hull cannot be at an optimum for both, and designs are the result of a series of trade-offs relating to the use of the vessel. Systematic series tests show that the frictional resistance depends on basic hull parameters such as length at waterline, maximum waterline width, draft, and underwater surface area. The optimum combination of these parameters changes with ship speed so that the designer must choose the most economical compromise.

At the low speeds used for trawling, hull resistance is minimal, minimum wetted surface becomes the important parameter, and canoe-like semicircular sections are optimal. In this situation, most of the thrust goes to pulling the trawling gear, and penalties for a non-optimum hull are not great. Frictional resistance, however, increases as the square of the speed, and wave resistance increases even more rapidly. Hull designs tend to become flatter and wider for the higher speeds used when cruising, particularly toward the rear of the vessel.

Proper hull design for a given trawling operation must then consider the amount of free-running time against that spent in fishing. The Mississippi study showed that, for most of the trawl fishing done by U.S. fishermen, the time spent trawling exceeds the time spent traveling to and from the fishing grounds. In general, there appears to be slight economic advantages favoring a low speed form that incorporates an angled propeller shaft. Without the inclined shaft, a significant proportion of propeller thrust serves only to change the position of the vessel in the water.



The effect of this is to increase low-speed resistance.

Since the individual fisherman is rarely faced with designing a vessel to suit his/her particular use patterns, but rather needs to determine how best to modify and use an existing vessel, tow tank tests by the Massachusetts Institute of Technology considered possible modifications of currently used vessels. It was shown that vessels can be economically retrofitted with a bulbous bow to reduce the bow wave and thus the high speed drag.

A wide variety of seaworthy hulls can serve as trawlers if the engine, reduction gearing, propeller, and trawling gear are properly matched. There is a problem in accomplishing this, however. If a fixed pitch propeller is designed to provide maximum towing force at trawling speed through a single speed gear, it will not be properly designed for the free-running condition. However, if it is designed to develop full power in the free-running condition, it will not be able to develop full power in the slow speed trawling situation. The designer is again forced to select the most economical compromise.

There are many types of practical marine propellers. Sea Grant studies have produced analyses for conventional single propeller driven systems that enable numerous design options to be compared. These equations indicate that large diameter, slow turning propellers are generally most efficient.

The computer model

Within the limitations discussed so far, there are numerous combinations of gear ratio and propeller characteristics that permit a given engine to function within its allowable operating zone. The designer or owner considering a possible retrofit must have some means of ensuring that no essential constraints are violated and of comparing the economic implications of alternatives.

Thus, a computer model was developed by Sea Grant researchers at the Webb Institute of Naval Architecture to permit rapid evaluation of the many design possibilities. The fisherman generally knows the best trawling speed for capture of the species he seeks (between 2.5 and 4.5 knots usually), and also the average distance to the fishing grounds as well as the total time for the trip. For any particular vessel dimensions, engine, gear reduction and propeller combination, the free-running speed (and thus the time left for fishing) can be calculated for any specified free-running RPM. Likewise, the available tow force can be computed for any specified trawling RPM. This is roughly proportional to the dollar value of fish caught per hour.

Fuel rates can then be computed, and total fuel costs for the trip can be estimated.

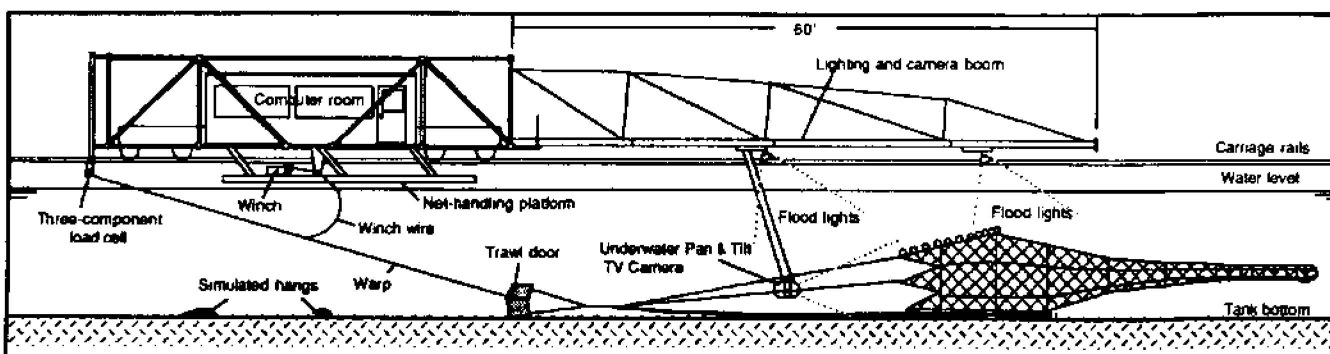
In both free running and trawling, the model checks the propeller and nozzle (if it is enclosed) for possible destructive low pressure conditions. The engine is checked to see if it is within acceptable torque and RPM limits. If any of these criteria are not met, the reason is printed. If the free running and trawling cases satisfy all criteria, the total revenue (value of fish caught minus cost of fuel burned) is calculated for the trip. Other economic factors such as crew costs, insurance, maintenance and mortgage payments are prorated per fishing day, and overall revenue before or after taxes can be computed for each trip.

Since the program allows specification of virtually any type of propeller, as well as diameter, pitch, gear ratio and RPM, a designer or owner considering a retrofit can predict the performance of various alternative propellers and configurations, and then compare them on an economic basis.

Improved engine design

Since the early analysis of the fuel cost problem indicated three probable areas for improvement, attention was also directed toward improved engine design. In a recent study by Sea Grant researchers at the University of Alabama, a diesel engine has been converted to use either conventional diesel fuel or methane. The result is a fuel and refrigeration system for fishing vessels that uses diesel for running speeds and methane for heavy-load operations such as trawling.

Liquified methane is stored in cylindrical stainless steel tanks. It enters the refrigeration system from these tanks as a liquid at about -260 degrees F and leaves as a gas at -10 degrees F, thereby providing three tons of direct refrigeration for the fish catch. Since liquified methane is priced 40 to 50 percent lower than diesel, an early economic analysis indicates a 30 to 40 percent saving on fuel costs and an additional 10 percent saving from the refrigeration that is provided.



A side view of the testing apparatus developed by MIT for trawl experiments in the DTRC towing basin.

Similarly, Massachusetts Institute of Technology Sea Grant researchers did an analysis and preliminary design of a Brayton-Cycle gas turbine for use on fishing vessels. Their studies showed that this engine would have an efficiency 10 to 30 percent better than advanced diesel, would have a lower initial cost, be smaller in size, and require less maintenance. To realize its fullest potential, the engine depends on the development of improved ceramic materials. Several manufacturers are moving cautiously toward this type of engine, but it will not be available in the immediate future. When fully developed, an additional advantage will be the useability of the power in the engine's waste heat for an onboard freezer.

Cost-benefit analysis

Although the technology for reducing the fuel cost burden is available, it usually requires a relatively heavy initial investment, which raises the question of whether or not the fuel savings generated by the vessel modifications are sufficient to justify the required investment. Many variables must be considered in order to answer this question correctly. Among these variables are the time value of money, the decision maker's tax bracket, the life of the equipment being considered, investment tax credits, the cost of fuel, the amount of fuel used, and the cost of money. Mississippi-Alabama Sea Grant developed a methodology that incorporates the effects of all these variables in a manner that leads to a correct "accept" or "reject" decision on any new fuel-saving technology.

Improvements in net design and usage through laboratory testing and at-sea observation

The third area targeted for study was net design. The efficiency of the fish harvesting operation is directly affected by net design because a well-designed net will catch more fish in less time, and also because the resistance of the net in the water consumes a large percentage of the vessel's fuel. Trawl net design has not been readily adaptable to mathematical description and computer methods. Exploratory studies are under way that may eventually change that situation, but so far this has been largely a trial-and-error art based on modifications to existing gear. A further complication is the fact that a particular net will act differently, and be more or less successful in catching fish depending on its rigging and other use factors such as towing speed. The individual fisherman is dependent on fishing lore and his own experience and instincts. This is especially true because he/she cannot see the net beneath the water while it is in use.

To make it possible for net designers (and individual fishermen) to "see" how their nets perform under different conditions, physical model testing facilities have evolved. Known as "flume tanks," these are essentially large rectangular tanks with windows on a side for viewing. Models of the net are held in place in front of the window, and water is circulated past the net, simulating the converse situation of the net being towed through the water. For bottom trawling, it is necessary to establish some friction with the bottom; this is approximated (poorly) by a bottom consisting of a moveable belt. Several of the largest and best of these facilities are in the U.K. and Denmark. There has been no comparable facility in the U.S., thus restricting the number of net manufacturers and fishermen who might have access to them.

Recognizing this need, Massachusetts Institute of Technology Sea Grant was encouraged to negotiate a memorandum of agreement with Navy's David Taylor Research Center to allow the use of their test facilities by MIT Sea Grant, and through Sea Grant, by U.S. net manufacturers and fishermen. These facilities include one of the largest flume tanks in the world, the test section measuring 22 feet wide, 9 feet deep, and 60 feet long. It allows the testing of models up to about a 1:6 scale ratio.

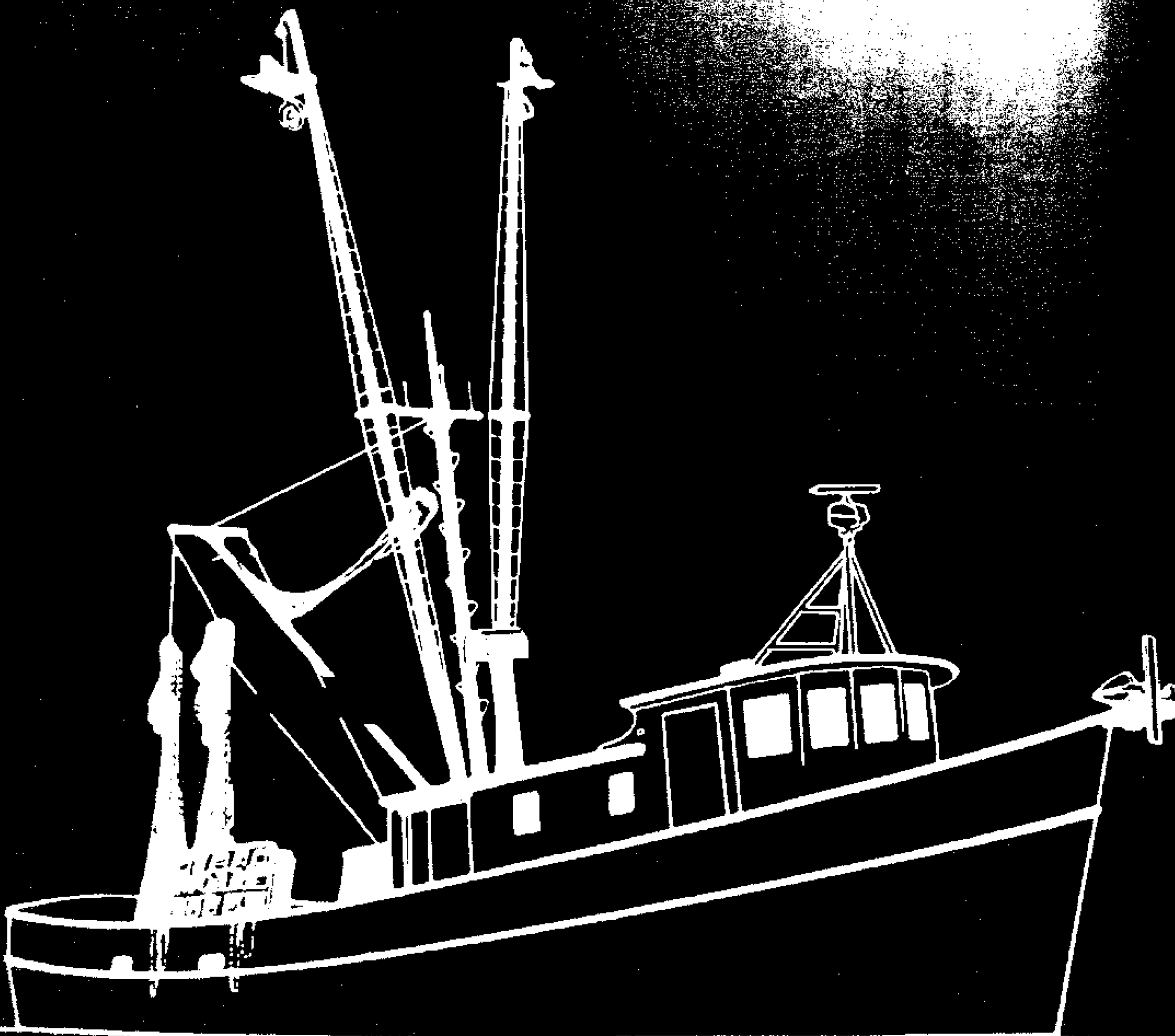
The flume tank is complemented by a tow tank that is more than 3,000 feet long and 50 feet wide, in which full scale models have occasionally been tested. Its size avoids the problems of scale distortion that are always present in the smaller flume tanks. A large tow tank has the added advantage of more correctly simulating the condition of motion over various bottom roughnesses and obstructions. This center is superior, for research purposes, to any fisheries research facility in the world. It has already been used for several years by U.S. net manufacturers, and their experience has been uniformly excellent. In addition, a fisheries engineer from the Massachusetts Institute of Technology regularly offers training courses to fishermen from various parts of the country, thus giving the fishermen a chance to "see" the effects of rigging changes and various net alterations. (*Introducing New Advances in Fishing Gear Technology* (next page) discusses fishing gear in more detail.)

Another relevant contribution by the Massachusetts Institute of Technology is the design of the Towed Underwater Gear Observation System, which is described in "Developing Unmanned Underwater Work Vehicles." This vehicle, which is now being manufactured and marketed by a Massachusetts-based company, allows for the underwater observation both of fishing gear in actual use and of fish behavior in the vicinity of the gear. This recent accomplishment is proving to be an invaluable additional research tool.

Conclusion

The fishing industry has been a focus of Sea Grant attention since the program's beginning. The uniqueness and strength of the Sea Grant concept are seen in this full spectrum approach of a carefully designed research program, formal education programs, and marine advisory activities to transfer the accumulated knowledge and wisdom to those who need it. This case study illustrates the Sea Grant approach of first analyzing the problem and then directing appropriate activity toward the solution of its various parts. Always coupled with the research activity is an educational/advisory effort to transfer the accumulated knowledge to those who need it for their livelihood.

— *Richard C. Kolf*



Introducing new advances in fishing gear technology

New and modified fishing gear is needed continually in the highly capitalized commercial fishing industry in order to: (1) allow fishermen to target new underutilized species, (2) fish on new grounds that offer challenges of bad bottom, tremendous depth, and/or heavy current, and (3) simply increase fish quality and fishing efficiency, although care is taken not to develop fishery capability further in already overexploited fisheries. Technology development of this type is an impossible task for the industry itself because of the costs, time, and risks involved.

In order to maintain commercial fishing as a viable, strong industry in the U.S. that can contribute to our negative balance of payments in the face of heavily subsidized foreign fishing fleets, the Sea Grant Marine Advisory Service (SGMAS) acts as a technology broker and facilitator in developing new gear so that fishermen can increase their productivity. Technology in one sector or geographic area is transferred to others, providing an international focus to these efforts.

The technology transfer process utilizes experimental approaches including flume tank simulation and real time demonstration using industry leaders as demonstrators in addition to the tried and true processes of workshops, classroom training, publications and one-on-one work with individual fishermen.

Gear development

Loss of endangered sea turtles in shrimp trawl gear has become a major issue with environmentalists and marine resource management agencies. A major development, the trawl efficiency device (TED), which was previously called the turtle excluder device, was first conceived and constructed by National Marine Fisheries Service (NMFS) gear specialists at Pascagoula, Mississippi.

The device, which is inserted into shrimp trawls, consists of a metal grid that deflects turtles out a spring-loaded trap door that is mounted in a metal frame sewn into the net. Working with the NMFS design, SGMAS programs in all Southeastern states have worked on a regional basis to introduce the TED to the shrimp fleet.

The original model was considered by some to be heavy, difficult to handle on deck, relatively expensive and a safety hazard. MAS programs throughout the Southeast have been instrumental in modifying the original NMFS design, both through their own engineering efforts and by soliciting innovative ideas from the shrimping industry itself. Several new designs, reduced in size and weight, have resulted. These designs generally consist of a metal grid or soft webbing inserted into the throat of a shrimp trawl that directs turtles and other large objects out of a precut hole in the net without greatly sacrificing shrimp retention.

NMFS and conservation organizations have developed an experimental protocol to certify the various TED models for use by commercial fishermen. Through an experimental process, TEDs must be proven effective at releasing 98 percent of the turtles captured in the net. Sea Grant programs, working with NMFS, have certified six different designs, including the original NMFS design. Efforts are now under way to fine-tune these TEDs to minimize shrimp loss.

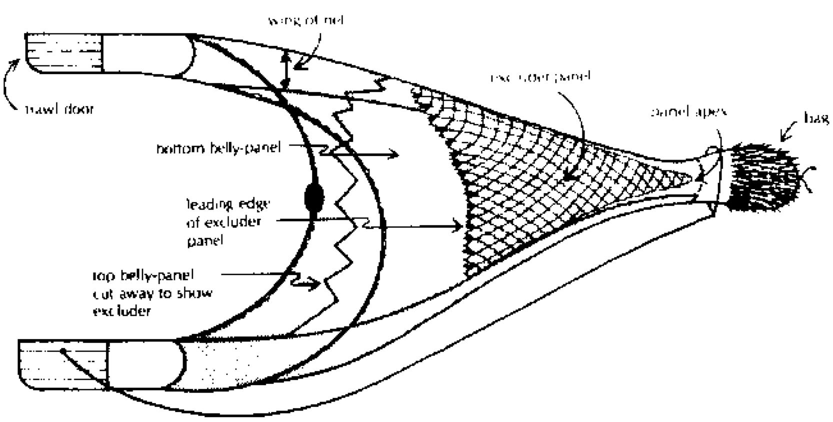
There will no doubt be some reduction in catch, especially over trashy bottoms, but some cooperating fishermen have seen losses lowered to less than five percent (95 percent retention of all shrimp caught) with well-tuned gear. Handling of the catch is considerably reduced because much of the trash is released through the TED, and quality of shrimp is significantly increased. The technology may also have application in reducing bycatch in other fisheries, a subject for future exploration.

While the use of TEDs is currently in legislative limbo, agency professionals feel the need to use them will soon be mandatory because of the overriding ramifications of the Endangered Species Act. When this happens, TED technology will be sufficiently developed that the industry should be able to respond with little economic impact. This has been a perfect example of an interagency effort that has resulted in technology development for future protection of several endangered species and, at the same time, has the potential for increased efficiency of operations and product quality.

Rhode Island and Georgia MAS programs have transferred European technology by introducing the "rock hopper" trawl to the East Coast groundfish trawl fleet. This trawl, which consists of a series of resilient rubber and fabric disks along the foot-rope of the trawl, is equipped to fish on exceedingly rough bottom, which was heretofore unfishable. SGMAS experts have recently refined and calibrated this gear to maximize its efficiency, and it is now widely used from Maine to Georgia as well as in Oregon. These programs were also instrumental in establishing U.S. outlets for components for making and repairing this specialized trawl, which has opened up thousands of square miles of previously unfishable bottom in the country's EEZ.

The rising price of fuel in the early 1980's prompted SGMAS gear experts in Alaska, Rhode Island and Massachusetts to work together to determine design parameters for trawls that minimize frictional drag and maximize areas fished in front of the net. This work, utilizing trawl models in flume tanks, resulted in use of much larger mesh in some parts of the trawl without sacrificing catch. This technology was transferred through trade journals and workshops. Fishermen who have incorporated these ideas into their trawl gear have realized fuel savings of up to 26 percent. Using the larger mesh also allows for bigger trawls towed at faster speeds to increase catch.

The Sea Grant Program at MIT developed technology to harvest surf clams using a hydraulic dredge in the early 1980's. This development greatly increased efficiency of harvesting these clams throughout the Northeast. As a result of SGMAS technology transfer to fishermen, surf clam landings have doubled since 1984, with an annual added value of more than $10 million.



The Morrison Soft TED

ROCK HOPPER TRAWLING GEAR

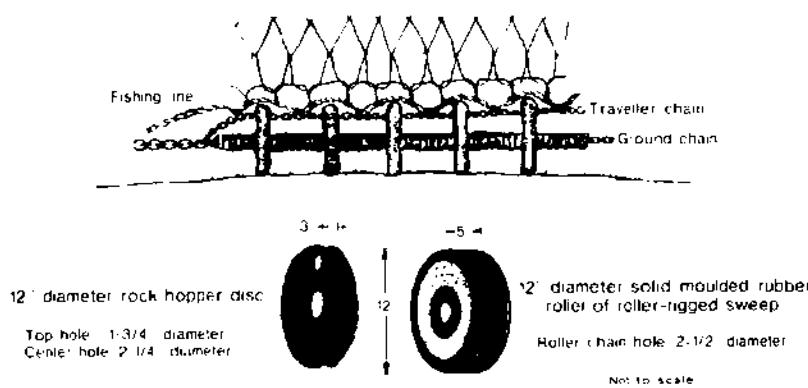


Diagram comparing a rock hopper sweep to a roller rigged sweep

Methods development

Many MAS activities related to increasing commercial fishing efficiency and catch involve developing new approaches with existing technology. For example, the traditional shrimp trawl, considered for 50 years as one of the most efficient harvesting devices in fisheries, has recently undergone significant change as a result of SGMAS gear development efforts.

The traditional shrimp trawl was modified by increasing the netting at the headrope and connecting it to a third towing wire, creating a "tongue," which increased the fishing height of the trawl and increased its efficiency. Then, using the technology developed for low drag trawls with larger mesh in the body and more efficient door designs, fishermen were able to tow two trawls, one off each side of their vessel, for the same cost as they formerly had in dragging one trawl. This trawling configuration allows fishing an area 47 percent greater than ordinary shrimp trawls with the same fuel consumption. This SGMAS technology development has gained almost universal acceptance in the U.S. shrimp fleet, and now four nets, two on each side, are becoming the norm.

Two-vessel trawling technology has been used by Europeans for many years as a way to increase size of gear towed with reduced fishing times for smaller vessels. Rhode Island SGMAS introduced this technology into the New England trawl fishery allowing small boats to fish economically for such species as haddock, cod, and pollock and pelagics. Ten "pair" trawling operations in New England doubled their landings in half the fishing time, and this technology seemingly will continue to develop among the small boat fleet.

Sea Grant research efforts have discovered harvestable levels of golden crabs, deepwater crabs inhabiting the Gulf of Mexico and Southeast Atlantic. Market demand has been created by test marketing the species through Sea Grant MAS activities in seafood technology, but mechanisms to catch these crabs economically need to be developed. The extremely deep water and currents in the Gulf Stream create problems for setting and retrieving gear that is not encountered in traditional crab fisheries. The Florida MAS program has developed a method to weight traps and set them long-line fashion in deep water, and it is now developing a retrieval method by grappling since currents sometimes prohibit use of marker buoys. Utilizing these developments, this fishery in Florida alone has grown in value to $1 million/year in two years and further expansion is certain.

Training

Alaska, Georgia and Massachusetts Sea Grant Programs all conduct unique training courses for fishermen and trawl manufacturers utilizing scale models of nets in flume tanks. Participants can actually see and measure the effect of changing various parameters, materials, and rigging schemes on actual trawl performance. They can then experiment with these variables to maximize actual fishing efficiency of their nets.

These training programs have demonstrated several benefits: (1) based on the tank tests, New England fishermen have documented higher catch rates, yet have modified cod-ends of their nets to successfully decrease juvenile fish mortality and increase quality, (2) participating U.S. trawl manu-

(continued on page 46)

National Sea Grant Network Participating Institutions

Alabama

Alabama Cooperative Extension Service
Alabama Marine Environmental Sciences Consortium
Auburn University
University of Alabama
University of Alabama, Birmingham
University of Alabama, Tuscaloosa
University of South Alabama

Alaska

Northern Southeast Regional Aquaculture Association
University of Alaska, Anchorage
University of Alaska, Cooperative Extension Service
University of Alaska, Fairbanks
University of Alaska, Fishery Industrial Technology Center
University of Alaska, Juneau

California

Bodega Marine Laboratory
California Institute of Technology
California State Polytechnic University, Pomona
California State University, Long Beach
California State University, Stanislaus
Claremont-McKenna College
Humboldt State University
Institute of Marine Science
Institute of Urban and Regional Development
Marine Bioassay Laboratories Marine Science Institute
Moss Landing Marine Laboratories
Point Loma College
San Diego State University
San Francisco State University
San Jose State University
Scripps Institution of Oceanography
Stanford University
University of California, Berkeley
University of California, Davis
University of California, Irvine
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
University of California, Santa Barbara
University of California, Santa Cruz
University of California Cooperative Extension, Davis
University of California Institute of Marine Resources
University of Southern California
University of the Pacific

Connecticut

Fairfield University
Institute for Marine & Aquarium Studies, Division of Sea Research Foundation, Inc., Willimantic
Project Oceanology
University of Connecticut

Delaware

University of Delaware

District of Columbia

American Geophysical Union
Howard University

Florida

Florida Atlantic University
Florida Institute of Technology
Florida International University
Florida State University
Harbor Branch Oceanographic Institute, Inc.
Mote Marine Laboratory
St. Petersburg Junior College
University of Central Florida
University of Miami
University of North Florida
University of South Florida
University of West Florida

Georgia

Atlanta University
Georgia Institute of Technology
Georgia Southern College
Morehouse Medical College
Skidaway Institute of Oceanography
University of Georgia
University of Georgia Marine Extension Service

Guam

University of Guam
University of Guam Marine Laboratory

Hawaii

University of Hawaii, Hawaii Institute of Geophysics
University of Hawaii, Hawaii Institute of Marine Biology
University of Hawaii, Hilo
University of Hawaii, Honolulu Community College
University of Hawaii, Kauai Community College
University of Hawaii, Leeward Community College
University of Hawaii, Manoa
University of Hawaii, Maui Community College
University of Hawaii, Windward Community College

Idaho

University of Idaho

Illinois

Loyola University
Southern Illinois University
University of Illinois, Urbana-Champaign

Indiana

Ball State University
Purdue University

Louisiana

Louisiana State University
Louisiana State University, Agricultural Center
Louisiana State University, Herbert Law Center
Louisiana Universities' Marine Consortium
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Sea Space Research
University of New Orleans
University of Southwestern Louisiana

Maine

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College of the Atlantic
Maine Department of Marine Resources
Maine Geological Survey
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Southern Maine Vocational Technical Institute
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University of Maine School of Law, Portland
University of Maine, Orono
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Washington County Vocational Technical Institute

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University of Maryland, Baltimore County
University of Maryland, Center for Environmental and Esutarine Studies
University of Maryland, Center for Marine Biotechnology
University of Maryland, Chesapeake Biological Laboratory, Solomons
University of Maryland, College Park
University of Maryland, Eastern Shore
University of Maryland, Horn Point Environmental Laboratories

Massachusetts

Boston University
Children's Memorial Hospital
Harvard University
Massachusetts Coastal Zone Management Office
Massachusetts Institute of Technology
Massachusetts Maritime Academy
Marine Biological Laboratory, Woods Hole
New Bedford Public School System
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Tabor Academy
University of Massachusetts, Amherst
University of Massachusetts, Boston
Woods Hole Oceanographic Institution

Michigan

Eastern Michigan University
Michigan Primary and Secondary Schools

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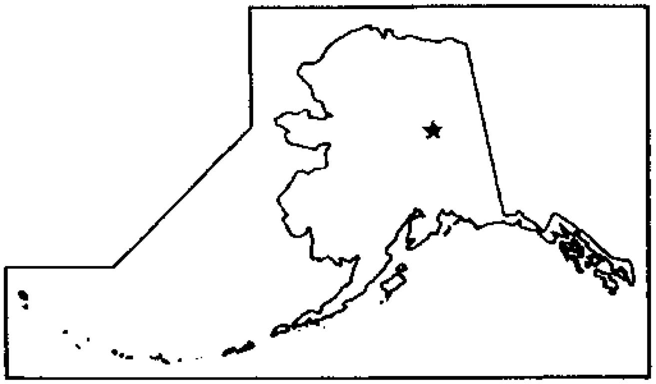

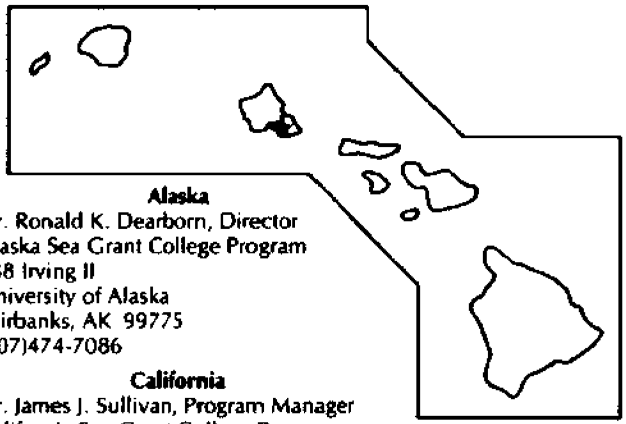

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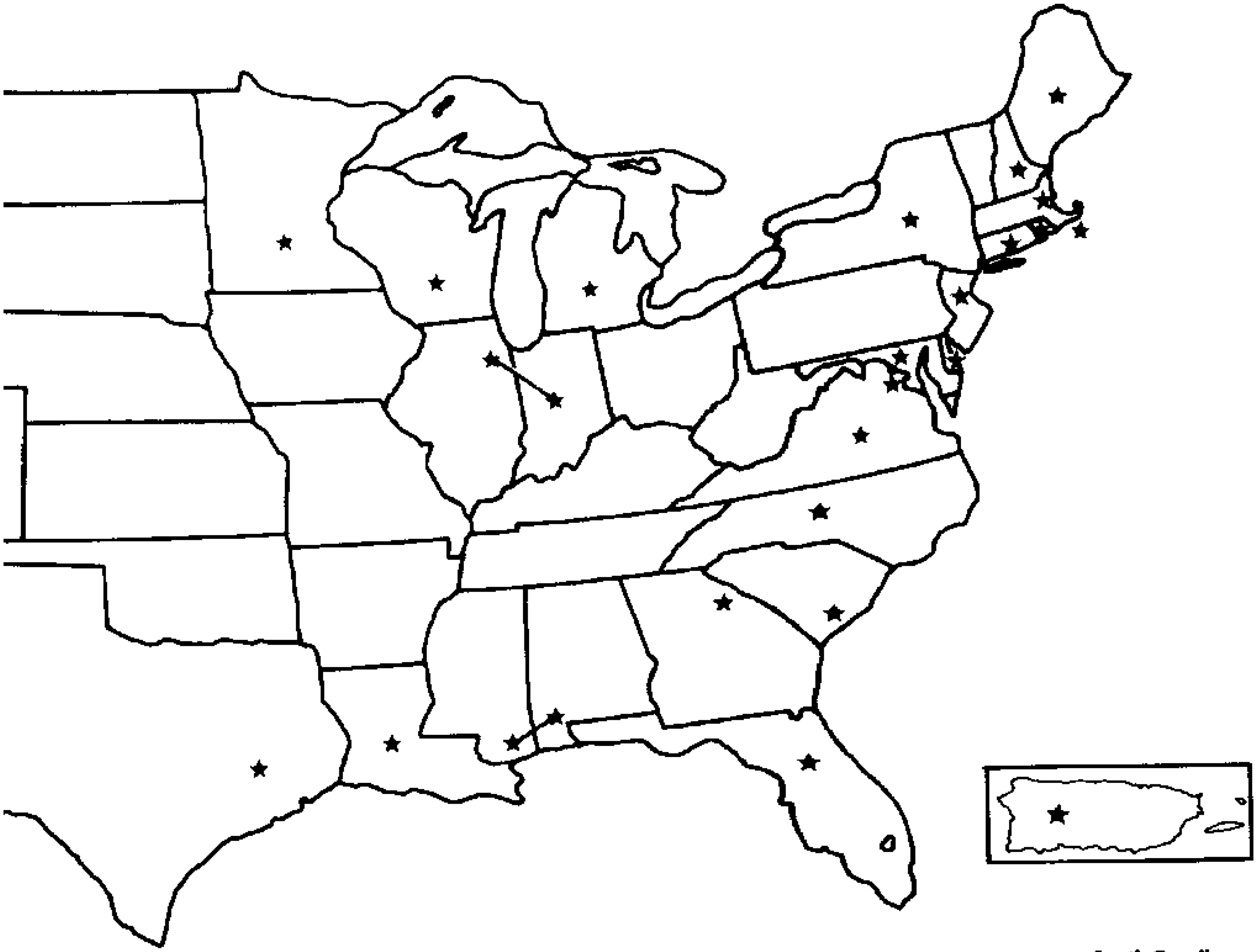

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University of Puerto Rico, Rio Piedras
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South Carolina Marine Resources Center
South Carolina State College
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University of South Carolina, Columbia
University of South Carolina, Beaufort
University of South Carolina, Coastal Carolina

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Texas A&M University at Galveston
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Texas Southmost College
Texas Tech University
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University of Texas, Austin
University of Texas, Port Aransas
University of Texas, Tyler

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University of Utah

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College of the Virgin Islands

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Hampton Institute
Keltech Inc.
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Virginia State University

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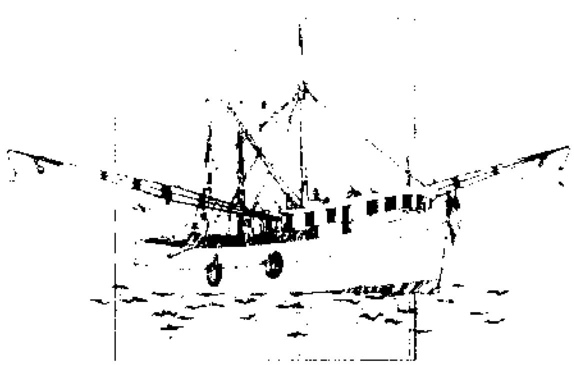
University of Wisconsin, System



Upgrading seafood science and technology

Since 1976 when the Magnuson Fishery Conservation and Management Act went into effect, commercial landings of fish at ports in the United States have increased from 5.4 billion pounds to 6.9 billion pounds in 1987, and foreign fishing in the U. S. Exclusive Economic Zone (EEZ) has decreased by more than 90 percent. During the same period, imports of edible fishery products increased by 44 percent and the national deficit in trade of all fishery products stood at a record $7 billion. This growing lack of self-sufficiency in fishery products results in part from an expanding population that consumes increasingly larger amounts of seafood (up 18 percent since 1976 to 15.4 pounds per capita annually) and lack of additional stocks of traditional species, particularly tuna, shrimp, and groundfish for steaks and fillets. The imbalance in trade is in part the result of declining commercial catch of some traditional species, and it will not be erased by advancements in seafood science and technology. However, research and education can slow its growth; alternative products and new by-products can reduce it.

In the fiercely competitive environment surrounding international trade in seafood, academic science plays an important role. Central to competitiveness is how productively industry can use its nation's limited resources. Also critical is the relative ability of domestic manufacturers to introduce new products and adopt new processes. Scientific advances and well-trained students are essential ingredients for success in an industry facing continuously changing problems and opportunities — an industry made up mostly of small companies without research divisions. Fewer than 30 percent have gross revenues greater than $1 million annually.

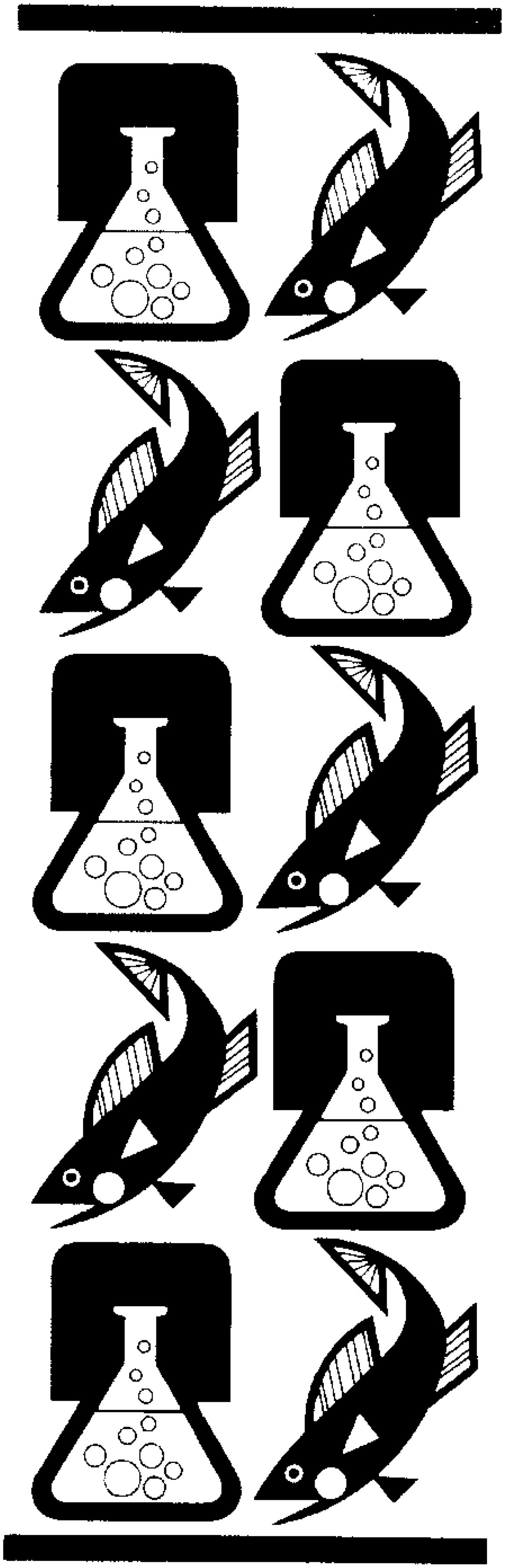
Sea Grant research

Because the public is becoming increasingly sophisticated in its seafood requirements, quality and, of course, safety are particularly important issues. Much of the increased consumption of seafood is in fresh and frozen fish, the quality of which can deteriorate quickly. A large proportion of food-borne disease in the U. S. is contracted from seafood, yet safe seafood seems to have special benefits in improving the cardiovascular health of those who eat it. However, seafood is out of reach for most consumers as a staple because of its high cost. It's expensive to process and has a short shelf-life. It is a luxury item, the most expensive source of protein in the American diet. Research may find ways to make certain types of seafood broadly affordable to the public, but this is only one issue. Sea Grant designed its program in seafood science and technology to draw academic talent to a spectrum of issues pertinent to strengthening an industry less advanced than other segments of the food industry. The program can be characterized by four types of effort:

- Developing equipment and engineering solutions to problems in processing and waste management,
- Developing technology for primary products and by-products,
- Developing the scientific basis for designating safe fishing grounds and seafood, and
- Improving efficiency and quality of processing and storage procedures.

Many problems and opportunities in these categories are of interest to academic scientists and amenable to their research methods. The cadre of academicians dealing with seafood, while too small and declining, had its primary development from 1969 to 1979 in response to growth of the National Sea Grant College Program and the importance it placed on seafood technology. Results of research in this field are accessible to users for three primary reasons: (1) a number of the researchers are also specialists in marine extension programs, (2) most of the researchers are known to the industry and have regular interaction with certain companies, and (3) the results appear in scientific papers and advisory bulletins.

The researchers and extension specialists collaborate across state lines or between institutions when appropriate. For example, when an outbreak of cholera traceable to seafood occurred on the Gulf Coast, researchers in Louisiana, Maryland, and Oregon joined to determine the bounds of the problem. They showed that the causative bacterium is a natural species in many marine environments, that it is not associated with sewage outfalls, and that seafood properly handled is not a source of infection. In June 1988 at the request of the Institute of Food Technologists, seafood specialists in the Florida, Louisiana and Virginia Sea Grant Programs joined with industry, the National Fisheries Institute, and the National Marine Fisheries Service to present a two-day educational work-



shop in seafood technology on the weekend preceding the Institute's annual convention. More than 80 food technologists participated at a cost of $350 each.

Engineering and waste treatment

Sea Grant's level of effort in engineering and waste treatment is small. Most of the research on control of wastes is in by-product development that is described in the next section. There have been few projects in development of machines and devices for processing seafood. Few projects of this type are appropriate for academic researchers, but certain kinds of engineering problems are appropriate and offer universities good opportunities to train students and aid the industry.

Engineering for the soft shell crab industry

Soft shell crabs form a small but growing part of retail trade. Moreover, potential domestic and foreign markets for soft crabs appear to be large, but a paucity of premolt crabs limits expansion of commerce. Recognizing these latent markets a few years ago, Sea Grant began efforts to increase production, improve the holding systems used in the industry, and design more efficient filters for them. This effort resulted in guidelines and engineering designs for increased capacity and better operation.

Recent research at Louisiana State University (LSU) has further defined improvements in systems for holding live crabs. LSU's high-rate filter with a fluidized sand bed removes solid wastes, provides a large surface area for growth of purifying bacteria, and eliminates the threat of clogging. This configuration provides high rates of bacterial removal of ammonia and nitrite. The LSU system has a carrying capacity 25 times greater than standard systems using submerged rock filters. The filters require pH control at peak loads, but this can be effected with sodium biocarbonate. LSU has consolidated its advances in a new design manual for commercial users. Largely because of Sea Grant efforts in research and technology transfer, the soft-shell crab industry has grown from $1 million annually to $16 million, with $4 million of this total in exports.

Product development and by-product recovery

Early on, the National Sea Grant Office emphasized by-product recovery as an important approach to dealing with seafood wastes. For example, recognizing that wastes from processing of shrimp and crabs represented a problem of growing significance, it paid for the pilot-scale production of chitosan, a natural polymer that can be derived from the chitin in shells. Chitosan was distributed free of charge in one-pound lots to any researcher requesting it. This spurred research worldwide; Sea Grant sponsored much of it in the U.S. **Bioprocessing Technology** (July 1987) foresees a $335 million annual market in the U.S. for chitin and its derivatives. Development of new products for domestic and foreign markets also aids expansion of commerce, and Sea Grant has invested in research to this end. It has advanced technology and enhanced trade. Research on minced fish and surimi is an example.

Surimi

Fishes traditionally used only for industrial products of low value or those not heavily fished are potentially viable as sources of surimi, a bland, white form of minced fish. Surimi is an intermediate step in making a wide variety of restructured products of high value such as simulated scallops. These products have the potential to greatly expand the market for seafood. Several Sea Grant projects have addressed the opportunity for use of certain fishes as minced product — some through development of fundamental information on their chemical and physical properties, others on processing factors that control quality. A team of scientists at North Carolina State University (NCSU) has conducted much of this research, documented its accomplishments in an important series of professional papers, and trained a dozen students for industry.

This research, in the Departments of Food Science and Civil Engineering at NCSU, had its origins in Sea Grant research of the early 1970's on minced fish technology. As the technology for minced fish and surimi developed, a basic research program also developed with the objective of defining ways to precisely manipulate the functional properties of proteins from fish and thus extend their usage in food manufacturing. From this work have come improved methods for testing and specifying both gelling properties and color and flavor/odor properties. Computer-based, least-cost formulations of surimi-based foods also have been developed. Unique properties of fish proteins, such as the ability to gel at very low temperatures, give these materials a functional advantage over competing food proteins in certain applications. The engineers have developed computerized schemes for ultrafiltration and water reuse that provide significant protein recovery and conservation of water. They also have determined optimum conditions for treating wastewater and developed mathematical models of the processing of minced fish.

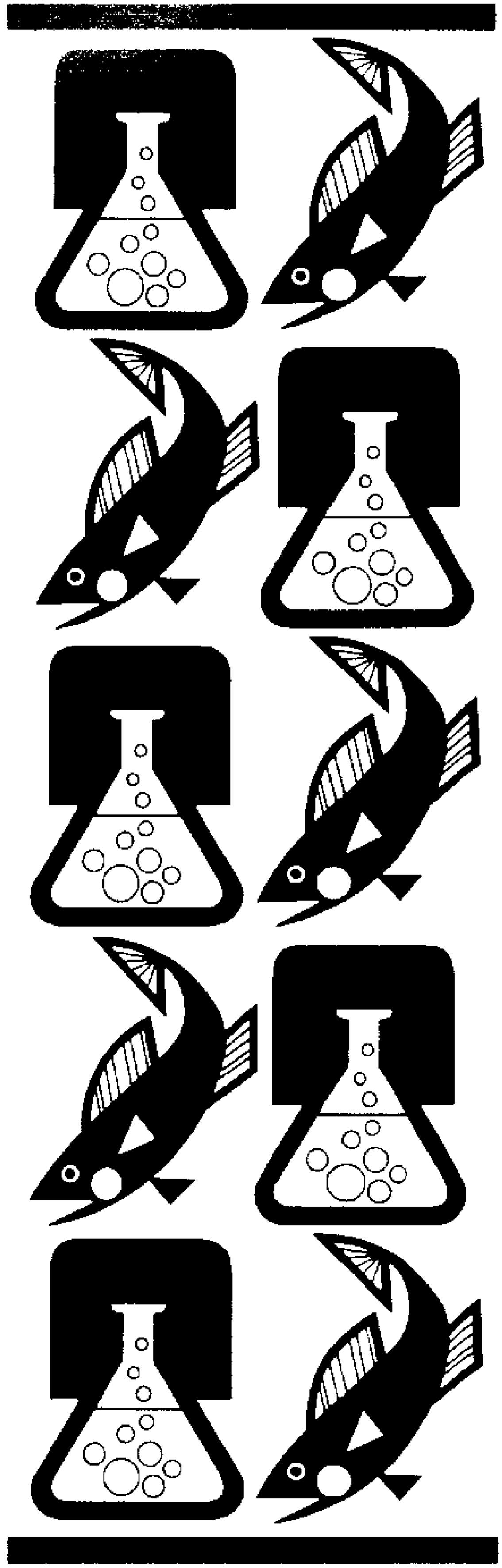
The NCSU scientists have worked with sand trout, Alaskan pollock, red hake, silver hake, Atlantic croaker, and menhaden. One aspect of the research on the effects of cyclic freezing and thawing on the quality of frozen surimi revealed that increasing the number of freeze-thaw cycles reduced the strength and deformability of surimi. The studies showed that these deleterious effects could be offset by various thermal pretreatments. The studies also led to a generic methodology for better defining properties of protein gels. Another aspect of the research showed that red and silver hake have excellent potential for surimi production. Besides producing a surimi of exceptional quality, the red hake is in good supply, has few other commercial uses, and is, therefore, a low-cost material. The researchers suggest that as the consumption of restructured seafoods increases, demand for surimi will force use of nontraditional food species. NCSU is now focusing on menhaden.

Equally important is the broad impact that the developing surimi industry is having on seafood quality. Research has demonstrated that tight control of temperature and sanitation during manufacture prevents denaturation and degradation that alter the physico-chemical properties of fish proteins and lower their value. Translated into practice, some fish processors are adopting sanitary procedures more stringent than those required for meat and poultry processing.

The successful research and training of students at North Carolina State University, funded jointly by Sea Grant and the National Marine Fisheries Service, was a prime factor in a surimi plant's locating in North Carolina. This new plant employs more than 50 people full-time with an annual payroll of more than $1,000,000.

Microbial, chemical and nutritional quality

Research on quality and safety deals with seafood as it comes out of the water, particularly in regard to contamination by pathogenic microorganisms, and with deterioration of quality during processing, transit and storage. Some projects focus on determining the environmental factors responsible for contamination of shellfish by viruses and bacteria or on procedures



Contamination of shellfishing waters is a problem

for accurately measuring and eliminating pathogens. A large proportion of coastal waters are closed to shellfishing because of concern over bacterial, viral or algal contamination. Obviously, this is a significant issue. In other projects, scientists are developing methods to deal with natural contamination of clams, oysters, and finfish by algal toxins that cause paralytic shellfish poisoning (PSP) and ciguatera. PSP causes enormous losses of resources in New England, the Pacific Northwest, and Alaska. Ciguatera inhibits development of fisheries in most tropical waters. Methods for predicting algal blooms and rapidly delineating fishing grounds contaminated with toxic microalgae would allow for greater use of valuable resources.

Bacterial and viral contamination

Contamination of shellfishing waters is a problem. The standard method for determining sewage pollution depends on detection of fecal coliform bacteria. However, this nonspecific method provides unreliable protection against specific diseases such as infectious hepatitis and non-bacterial gastroenteritis. Thus, Sea Grant researchers have taken a number of approaches to alleviating this problem. At Louisiana State University, they developed and evaluated methods for the extraction of enteric viruses from oysters and completed a study of their occurrence in oysters and overlying waters. They found that enteric viruses can be present in waters considered safe on the basis of standard assays. In related studies after an outbreak of viral gastroenteritis in 1982 that closed many oyster beds and cost the fishing industry millions of dollars, scientists at Nicholls State and Louisiana State Universities detected entero-viruses in water samples only during the coldest months when viruses could persist for longer times. However, they found no statistical correlation between levels of fecal coliforms and presence of enteric viruses in either the oyster meat or the overlying waters. These results further debase use of assays based on indicator bacteria.

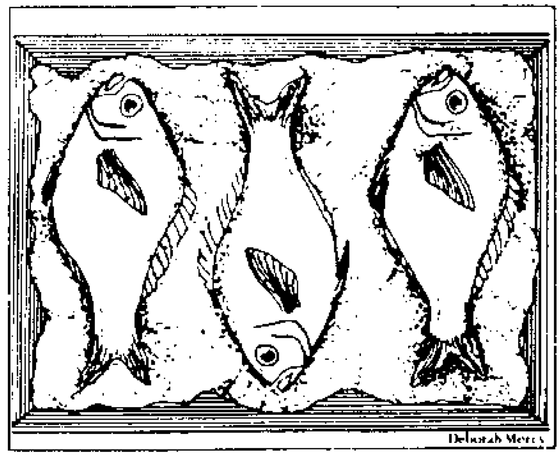
A majority of viruses from sewage is associated with suspended solids that prolong their survival. In order to quantify the relationships between viruses and solids, virologists at Baylor College of Medicine studied viruses in Galveston Bay. The viruses often were attached to suspended solids on which they could remain infectious for up to 19 days. The researchers showed that collecting suspended solids for viral analysis has advantages over collecting and processing large volumes of water. They also developed a nucleic acid (cDNA) assay for the detection of hepatitis A virus in estuarine samples and a highly sensitive, enzyme-linked immunosorbent (A-ELISA) assay that does not require the use of radiolabeled reagents in detecting this virus in estuarine samples. Their studies indicate that these new methods will be useful in more precisely monitoring the environment.

Modified atmospheres

Researchers at the University of California have examined the microbial and safety implications of using modified atmospheres (mixtures of innocuous gases) to extend the storage life of fish. They have focused on the bacterium *Clostridium botulinum* and determined that, in the case of red snapper, temperature and storage time, but not storage atmosphere, significantly affect probability of toxigenesis. Using linear regression models, they derived equations that can predict the probability of one spore initiating growth and toxigenesis at a particular time and temperature during storage. They showed that naturally occurring levels of *C. botulinum* will not intoxicate fillets stored at 4°C for up to 21 days. At an abusive temperature (8°C), even one spore can cause toxicity before spoilage is obvious. This predictive approach is a powerful tool in defining microbial interactions with food.

Handling and processing

This research covers a variety of approaches to improve handling and processing practices — in some ways, "bread and butter" issues because the results are often immediately useful to agents and specialists in technology transfer. Sea Grant has focused a number of recent projects on processing and storage of molluscan shellfish. For example, in efforts to extend the shelflife of calico scallops, food scientists in Georgia and Florida examined and compared a number of processing practices. They developed and published quality control procedures and a bulletin that outlines considerations for plant location, layout, construction, equipment, and personnel. The bulletin also covers



inspection schedules and methods, cleaning, sanitation, product quality and grades, and product description and evaluation. It provides a list of relevant regulatory agencies.

Freezing methods

Vacuum-packed seafood products, such as shrimp and crab, are major products in the Pacific Northwest. A variety of packing techniques are used in the shrimp industry, with vacuum packing in cans most common. The cans are frozen either directly in an airstream or after packing in cardboard cartons. Because reliable information on freezing rates is unavailable, application of poor procedures is common. Resulting problems can cause slow freezing that lowers quality and efficiency and wastes energy. Thus, engineers at Oregon State University began studies to measure freezing times under various packaging and stacking conditions, investigate how various conditions affect freezing rate, compare experimental freezing times with published prediction methods, and specify improved processing methods. Vacuum level had little effect on the freezing time, but packing technique was a key issue. Freezing times for stacked cans were 30 percent longer than those for unstacked cans. Enclosing the shrimp cans in a carton doubled the freezing time.

Fresh flavors

Researchers at the University of Wisconsin took another approach to improving quality of seafood by determining the chemistry of fresh and spoiled fish flavors — factors very difficult to control. Their results can be applied toward providing longer-lasting, better-tasting products. Using modern techniques of microanalytical chemistry, the researchers were able to define enzymatic mechanisms by which compounds responsible for flavor and aroma are produced. They showed that the nine-carbon volatile alcohols and aldehydes responsible for much of the aroma of cucumber and melon fruits also occur in some species of fish such as whitefish, ciscoe, smelt and spawning Pacific salmon. They also showed that oxidatively-derived carbonyl compounds that smell bad can be detected in harvested fish held just one day on ice. Fish spoils rapidly and off-flavors can develop long before any nutritional or safety factors are measurable by normal procedures. The researchers' results have enabled them to prolong shelf life of some fish from six to eight days to nearly two weeks. They also have more than quadrupled the storage time of some types of frozen fish to over a year.

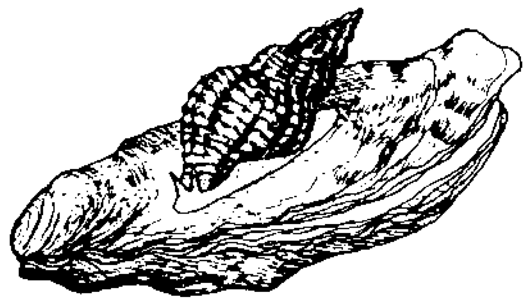
Conclusion

From the inception of the National Sea Grant College Program, its managers recognized the importance of applying food science and technology to problems and opportunities in the seafood industry. As a result, they encouraged and supported projects that brought fish and shellfish into academic departments that had previously dealt only with poultry, beef, pork, and vegetables. The few departments that already dealt with fish were able to expand their research and educational activities relating to seafood. A cadre of academic scientists developed in the coastal states that has proven highly effective in solving problems and exploiting opportunities in research, education and advisory service for the seafood industry and consumers. They were responsible for establishing the seafood technology group in the Institute of Food Technologies. This group now has several hundred members.

Sea Grant expanded its research and educational activities relating to safe and competitive use of fishery resources until the early 1980's when level funding and inflation began a long decline in level of effort. However, needs for research, education, and service continue to grow, and there is mounting discouragement among academic leaders and industrial representatives that a lack of resources is stymieing preparation of a second generation of scientists and advisory specialists to serve the public and industry.

Important problems and opportunities ripe for research and relevant to health of the industry continue to present themselves. For example, the U.S. trade deficit includes a $3 billion deficit in trade of nonedible products. As much as $200 million of these imported, nonedible fishery products, such as hormones, fatty substances and fish meals, derive from processing wastes and industrial fish. A greater level of research on byproduct recovery could reduce this import dependency while ameliorating problems in waste disposal. The opportunity to continue upgrading a comparatively backward segment of the food industry remains an important challenge.

— *David H. Attaway*



Investigating Parasitic Diseases of Shellfish

When European settlers first came to North America, they were amazed at the quantity and accessibility of clams and oysters.The humblest of colonial era recipes called for shellfish ingredients, indicating that these seafoods were considered staples rather than, as today, delicacies. By the end of the 19th century, overharvesting and industrial and municipal pollution had all but eliminated many littoral stocks of clams and oysters. However, deeper water populations and those located in less populated coastal and estuarine areas were sufficient to meet general demand. At the turn of the century, commercial harvests of oysters peaked at such famous producing areas as Long Island Sound, Delaware Bay, Chesapeake Bay, Puget Sound, and San Francisco Bay. Since that time, commercial harvest levels have dropped to such an extent that only the Chesapeake supports an entirely wild oyster fishery, and today even that is threatened.

In addition to overharvesting and pollution, degradation of habitat, lack of appropriate clean cultch, and disease have contributed to oyster stock declines. Of these, the consequences of diseases are the most devastating. In the early 1950's, the parasite MSX, *Halosporidium nelsoni,* was first identified as the cause of oyster mortality in Delaware Bay. By the end of the decade, virtually all oysters in the high salinity portions of the bay had died. The disease then spread into the Chesapeake Bay where it destroyed oyster beds throughout the Virginia portion of the bay. During dry summers, MSX spreads into oyster producing areas of Maryland. Oyster producing areas from Massachusetts to Georgia are infected with MSX and in the summer of 1987, these areas experienced mass mortalities attributed to MSX.

Among the shellfish beds of the Gulf and Southeast states, another disease called dermo is the major source of mortality among oysters and clams. Dermo is caused by the parasite *Perkinsus marinus*. Although dermo is most common in southern states, this disease also affects shellfish populations along the entire Atlantic Coast. Financial losses attributed to dermo are estimated at millions of dollars per year. Along the Pacific Coast, heavy exploitation and pollution were primary factors in the collapse of the native oyster fisheries; however, a flagellated protozoan, *Hexamita* was associated with some oyster mortalities. Shellfish diseases are not unique to the United States. Parasitic diseases are recognized as the major cause for the collapse of oyster and clam fisheries and aquaculture ventures throughout Western Europe and extensive portions of the Far East. To date, all attempts at seeking relief from these diseases have resulted in modest success.

Sea Grant research

As parasitic shellfish diseases spread throughout the most productive and economically important shellfish areas of the United States, Sea Grant joined with state and, to a lesser extent, federal agencies in pursuing research aimed at restoring disease-infested waters to their historic levels of productiveness. Sea Grant's approach is a program consisting of research in parasitology, genetics, and physiology integrated with aquaculture and hydrodynamics. Although not yet a complete success, Sea Grant is making considerable progress in this seemingly intractable and perplexing problem.

Both MSX and dermo are caused by protozoan (single-cell organism) parasites that are characterized by having a life stage called spores, thus their scientific name sporozoans. Like many parasites, the sporozoans have complex life cycles requiring different hosts at different life stages. If the appropriate host is not available at the right time, the parasite will die. Thus, the easiest way to control the disease is to, in some way, break the life cycle by either eliminating any one of the host organisms or reducing the degree of contact between the infectious host and the shellfish. Since the onslaught of these diseases, researchers throughout the nation have attempted, with no success, to identify the intermediate hosts of the parasites. They have also attempted to address the perplexing related issue of why, under normal conditions, healthy shellfish are not infected when held together with diseased animals.

Although Sea Grant supports research in MSX and dermo life cycles, the network focuses on developing alternative solutions for dealing with these diseases and thereby restoring shellfish productivity to infected coastal waters. The approach taken by Sea Grant is divided into two well-integrated components, one stressing fundamental research on life cycles and shellfish physiology and immunology, and the other developing techniques and methodologies for managing around the problem.

Fundamental research

Sea Grant research on solving the life cycle of MSX and dermo has met with limited success. Investigators have attempted to use florescent antibodies developed from spores of the parasite to trace spores ingested by oyster scavengers. Spores were ingested but results were inconclusive as to the transmission of the disease. Work on the dermo life cycle was similarly inconclusive with respect to identifying infective hosts.

However, Texas Sea Grant researchers were able to demonstrate for the first time that disease-free oysters infected by the parasitic marine snail, *Boonea impressa,* invariably come down with dermo. Although dermo does occur among oysters unexposed to the snail, this is the first inkling of how this disease may be transmitted.

Because of the failure to make critical inroads on the problem of life cycles, Sea Grant began to focus on the potential of disease resistance. Seizing upon the opportunity presented by a laboratory population of apparently MSX resistant oysters produced at Rutgers University, Sea Grant scientists initiated studies on the immunological mechanisms among mollusks. These investigations suggest that disease resistance is related to physiological conditioning rather than the immunological responses known for higher animals. Thus it is hypothesized that if high quality oysters can be produced by means of aquaculture, they could withstand MSX for longer periods than naturally produced seed stock.

Managing around the problem

Recognizing the limitations of traditional types of research, Sea Grant concurrently embarked upon a research program designed to increase production in disease-infected areas by working around the problem. Shellfish are produced in infested areas by harvesting animals from disease-free, low salinity waters, planting them in the high growth, high salinity water, and then harvesting them before the disease kills them. The problem with this practice is that success and failure of the crop depends on the ability to detect disease early enough to begin harvests before the animals begin to die.

Sea Grant researchers sought to develop diagnostic tools capable of rapid detection. To date, Sea Grant has made excellent progress in developing, through biotechnological means, an enzyme-linked immunosorbent assay (ELISA) for detecting MSX. This past year, Sea Grant also developed an ELISA test for dermo. ELISA tests shorten the time for diagnosis from three days to a few hours and allow a greater number of tests to be conducted.

Even more encouraging than the development of diagnostic tests is Sea Grant's work in evaluating and introducing disease-resistant oysters to aquaculture and into the wild. Again, building on the opportunities presented by the availability of stocks of disease-resistant oysters, Sea Grant initiated a program to determine if the stocks are significantly resistant to MSX and whether the growth rates of these oysters and meat quality are equivalent to nonresistant stocks. The objective of these ongoing studies is to provide, through mass aquaculture techniques, seed oysters that are suitable for high salinity water. If these stocks prove satisfactory, thousands of acres of formerly productive oyster growing areas can be devoted to full-time shellfish culture.

In associated research, Sea Grant scientists are attempting to introduce self-sustaining populations of oysters

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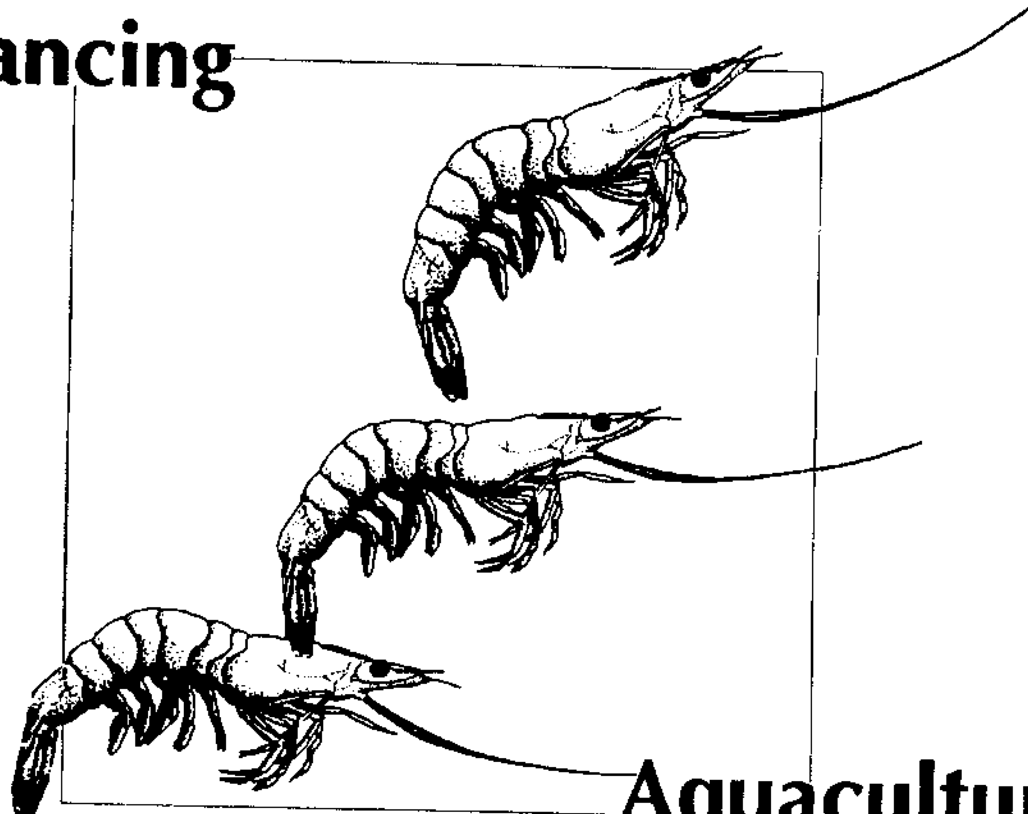
Advancing Aquaculture



The 1990's will see a major shift away from dependency on wild populations of marine seafood species and a greater reliance on aquaculture to supply the growing demand for seafood in the United States. Per capita consumption of seafood has risen from 12.3 pounds in 1982 to 15.4 pounds in 1987, yet most traditional U.S. fisheries are being harvested at or near maximum sustainable yields. Many fisheries have actually declined in terms of catch.

In 1987, the United States imported 3.2 billion pounds of edible fishery products valued at $5.7 billion. Fishery exports totaled $1.6 billion leaving us with a $4.1 billion trade deficit in edible fishery products. This is one of the largest trade deficit areas for the United States. This situation does not have to persist because we now have the mechanisms and technology to produce the necessary seafoods at home while creating jobs and new industry at the same time. Aquaculture of both freshwater and marine species will become increasingly more important in offsetting the shortfall of aquatic foods.

As a result of past research, by both the public and private sectors, dramatic aquaculture production increases have already occurred. In 1985, United States aquaculture production was about 535 million pounds. This was up 100 million pounds over the 1983 estimate. Aquaculture production for 1990 is estimated to be 700 million pounds, and for the year 2000 about 1,000 million pounds. Additional technology development in aquaculture will result in even greater gains and the availability of a much wider selection of marine products.

Sea Grant research

The National Sea Grant College Program has been the main funding source for aquacultural research in marine and estuarine species since the late 1960's. Much of the technology in use today on such valuable species as lobster, shrimp, salmon, clams, oysters and marine fish has been the result of Sea Grant research.

The Sea Grant aquaculture program has constantly adjusted to new opportunities and scientific advances. Guidance and coordination for the overall program comes from the aquaculture specialist at the National Office. Peer review is sought for each project and distinct program areas are investigated in a systematic and integrated way. This approach has been successful in developing new technology that can be used by industry to overcome production barriers.

Sea Grant has funded between 100 and 120 projects each year valued at $7 to $8 million when non-federal matching funds are included. Through the years, several categories of projects have been emphasized. These are:

- Aquaculture Systems
- Genetics/Selective Breeding
- Physiology/Endocrinology
- Nutrition
- Disease/Parasites
- Policy/Economics

In general, a species that is a candidate for aquaculture production goes through several stages of development related to these categories. The following are representative examples of Sea Grant's role in providing the scientific and technological basis for a few of the more economically important species.

Shrimp

In the late 1960's, it became apparent that domestic supplies of shrimp were insufficient to meet domestic demand and that the value of imports was increasing dramatically. The price of shrimp was increasing and an opportunity was developing for the production of farm-raised shrimp.

Sea Grant supported the first work on shrimp at the University of Miami in the early 1970's. Hatchery techniques were developed for pink shrimp and a manual for hatchery production using wild caught females was developed. Other NOAA researchers at the NMFS laboratory in Galveston, Texas, then developed hatchery methods for white and brown shrimp. Sea Grant researchers at Texas A&M University, using hatchery-produced shrimp from wild caught females, then were able to produce commercial quantities of white shrimp in ponds on the Texas coast.

After this work on developing the systems necessary for culture of shrimp, Sea Grant researchers, seeing the prospects for improving stocks through hybridization and selective breeding, began work in reproductive control of the commercial shrimp species. The next step was to induce spawning of shrimp in captivity using physiological and endocrine control. This was first accomplished in 1981 by Texas A&M University with shrimp endemic to the Pacific Coast of Central and South America. These shrimp proved easier to mature in captivity and grew faster and survived better in pond trials. Diet, photoperiod control, and temperature were found to be very important in controlling the quantity and quality of eggs and shrimp larvae produced from spawning stocks in captivity.

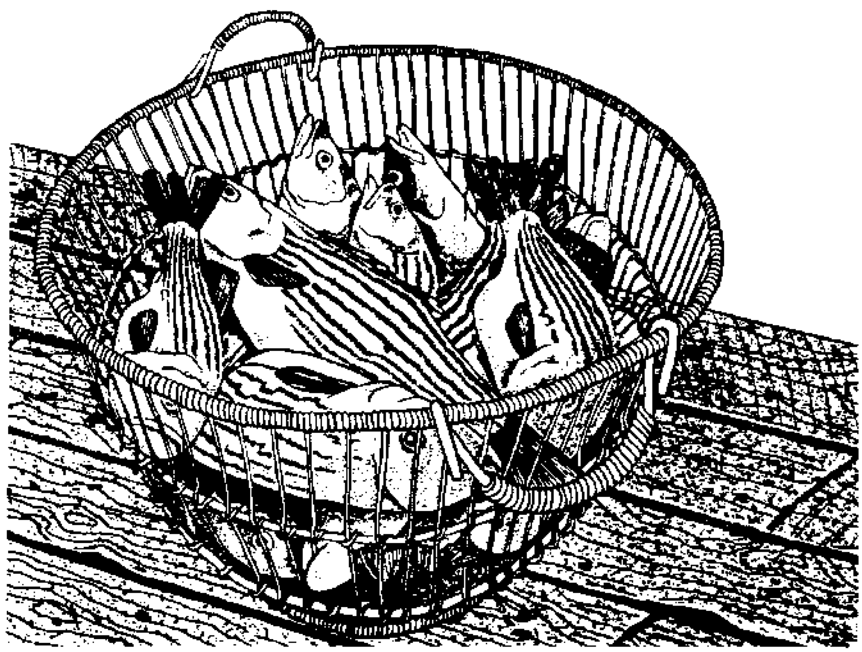
Another Sea Grant researcher in South Carolina, building on technology developed for artificial insemination of lobster and freshwater prawns, succeeded in obtaining spermatophores from marine shrimp through electrical stimulation. This led to the first hybrid shrimp cross between white shrimp and blue shrimp, which was accomplished at Texas A&M. After reproduction of captive marine shrimp became routine, pond studies and economic analyses at South Carolina and Texas A&M showed that shrimp culture should be commercially feasible.

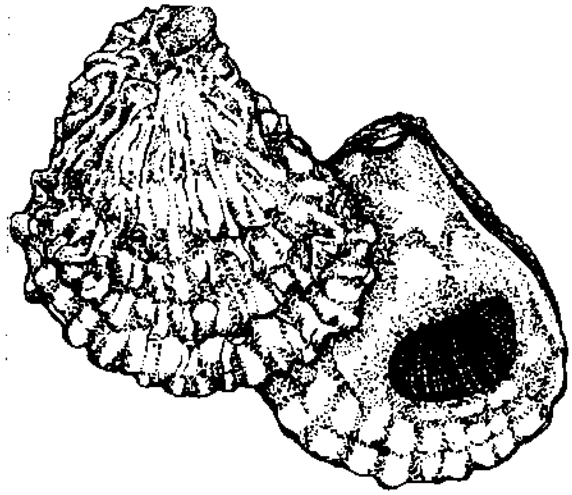
The technology developed through Sea Grant research led to the establishment of several shrimp farming companies in Texas, Hawaii, Florida, and South Carolina. A pilot scale shrimp farm demonstration at the new Waddell Mariculture Center in South Carolina yielded more than 5,000 pounds per acre in six acres of ponds in 1986 and close to 10,000 pounds per acre in 1987. One Texas shrimp farm produced more than 200,000 pounds of shrimp in its ponds in 1986, with even greater production expected for the future. The projected value of the developing shrimp culture industry is several million dollars a year, and more technological breakthroughs could lead to an industry that is worth tens of millions per year.

Striped bass/hybrid striped bass

The culture of striped bass dates back to the turn of the century but it was not until the mid-1960's, when the use of hormones to induce spawning came into wide use, that fry could be produced on a reliable basis. Pure striped bass proved hard to work with because of the large size of the females and the delicate nature of the species when placed under captive conditions. A second technological development, the hybridization of striped bass with white bass, created a much stronger fish that exhibited hybrid vigor and was quickly accepted and stocked in many parts of the country because of its exceptional qualities as a sport fish.

Sea Grant became interested in hybrid striped bass in the mid-1970's when it became obvious that the hybrid was vigorous enough to be considered for production as a food fish. This effort was stimulated in part because of declining stocks of striped bass, particularly along the East Coast; the need for a substitute white fleshed fish in the market place; and the need to stimulate coastal economies that were suffering from the collapse of natural fisheries.





Sea Grant research has accomplished several major breakthroughs that have brought hybrid striped bass culture to commercial feasibility. Researchers in both North and South Carolina have simplified the procedures for the hybrid cross so that smaller, more manageable male striped bass can be crossed with the small white bass females. This has allowed the maintenance of brood stock at hatcheries under captive conditions. This in turn has allowed researchers to develop environmental controls of the reproductive process so that brood stock can be made to spawn out-of-season, thus providing for earlier stocking of production ponds.

Even after the difficulties of providing reliable hatchery production of hybrid striped bass had been worked out, there was still a need to develop reliable nursery procedures to provide stockable sized fish to the commercial growers. Sea Grant researchers in both South Carolina and North Carolina helped develop the procedures for pond production of fingerlings which are now being used throughout the developing industry. Pond production trials established appropriate stocking densities and feeding regimes and showed that production could reach 7,400 pounds per acre at harvest. Routine production of 4,000 to 6,000 pounds per acre was achieved in other production trials.

With this production information, it was then possible to do economic analyses of the potential for hybrid striped bass farming. This analysis led to a 18-acre pilot project in North Carolina that is guided by Sea Grant extension personnel, and the first commercial crop of hybrid striped bass is now being harvested. During the course of production, the fish experienced an infection of a parasite that could have caused total mortality. However, earlier research by another Sea Grant researcher in North Carolina had clarified the environmental tolerances of the parasite, and the farmer was able to add freshwater to the brackish water ponds and lower the salinity to the known lethal limit of the parasite. Consequently, the infestation was eliminated. This is a perfect example of how Sea Grant basic research can be transferred and utilized to obtain practical results. The value of the production from the pilot project is estimated at more than $250,000, or almost $14,000 per acre, which is considerably more than can be obtained from traditional agriculture crops.

Oysters

The current U.S. oyster industry has suffered almost a total collapse compared to production levels at the turn of the century. Loss of habitat, pollution and environmental stress, and disease have all acted to decrease oyster yields. Natural oyster beds also suffered from mismanagement and neglect as there was no direct ownership due to the historic open fishery policies of most states. Those few states that allowed private leasing of oyster production areas noted that private grounds consistently outproduced those grounds in the public domain. It has become apparent that the culture of disease resistant, genetically improved, hatchery produced oysters in privately controlled production systems is one of the best approaches to revitalizing the oyster fisheries of the U.S.

With the above philosophy in mind, Sea Grant has funded many projects on oysters to improve the feasibility of culturing them. A long-term study at the University of Delaware established techniques of culturing oysters in semi-closed, recirculating systems. This work provided techniques for growing algal foods in commercial quantities, designed improved water treatment systems for reusing seawater and controlling oyster diseases, initiated work on artificial diets for oysters, and helped develop superior strains for culture under controlled conditions.

Two oyster diseases, MSX and dermo, are responsible for the majority of oyster mortalities on the East and Gulf Coasts, particularly in Chesapeake Bay and in Delaware Bay. Realizing this, Sea Grant has maintained a continuing program related to the diagnosis and control of MSX and dermo. Progress is being made on developing disease-resistant stocks through selective breeding, and field trials are now in progress to evaluate various disease-resistant stocks.

Sea Grant has also been instrumental in reestablishing an oyster industry on the Pacific Coast. The Pacific oyster industry, which was based on a small endemic species, was in very poor condition due to overfishing and habitat degradation when Sea Grant researchers at the University of Washington and the University of Oregon began experimenting with the larger Japanese oyster *Crassostrea gigas*.

Originally, Japanese oysters were imported as juvenile oysters attached to shells, but as production increased, oyster hatcheries were established to produce the Japanese oyster in the U.S. Sea Grant researchers helped refine hatchery techniques and later worked on improvements for outplanting young oysters to the production beds. Further work led to the development of remote setting technology that permitted the oyster farmer to buy oyster larvae from the hatchery and set them on his own cultch material. This reduced the costs of oyster farming considerably.

The Pacific oyster industry based on the Japanese oyster was moderately successful but in some years high summer mortalities of the oyster stocks were experienced. The mortalities seemed to be associated with high water temperature and loss of vigor due to excessive reproductive activity by the oysters. Previously, Sea Grant researchers at the University of Maine had experimented with manipulating chromosome number in oysters in order to obtain a sterile oyster. Oysters were created that had a complete extra set of chromosomes, a triploid oyster, that made them sterile and resulted in faster growth rates.

Sea Grant researchers at the University of Washington thought that a sterile oyster might solve the summer mortality problem being experienced by the Pacific oyster industry. They applied the technology developed at the University of Maine for the eastern oyster to the Japanese oyster and obtained a triploid oyster. As most oysters harvested in the Pacific oyster industry are produced in hatcheries, this situation provides the opportunity to manipulate the chromosome number on large numbers of oysters. Initial trials with a triploid Pacific oyster showed that it grew faster and maintained high commercial quality throughout the year. Now most hatcheries are producing triploid, sterile oysters for year-round marketing of oyster products, thus stabilizing the industry and increasing income for producers.

Technology transfer and manpower development

Sea Grant provides funding support for workshops and symposia to bring investigators together to determine status and chart future research needs. These workshops are frequently conducted by Sea Grant Marine Advisory (Extension) Service personnel who make sure that industry representatives and academic researchers have an opportunity for information exchange. Extension personnel are also involved in identifying legal, social, and other institutional obstacles to the aquaculture industry and working within legal and regulatory systems to get necessary changes for development to occur. In recent years, workshops have been held on the culture of marine shrimp, freshwater shrimp, hybrid striped bass, red drum, clams and oysters, biotechnology, legal and regulatory constraints, aquaculture engineering and other topics. In most cases, information presented in these workshops is published as a proceedings volume so that it can be used by the industry and general public that have an interest in aquaculture.

Perhaps one of the greatest benefits of the Sea Grant aquaculture program has been its support of many graduate and undergraduate students that have now become leaders in the field of aquaculture. Sea Grant alumni now manage shrimp farms, fish farms, oyster and clam hatcheries, salmon farms and ranches, and they participate in a multitude of other industry positions. Each year many of the 100 plus projects supported by Sea Grant include support for students. Over the years, this support trained hundreds of young people who are now instrumental in developing the future course of U.S. aquaculture.

Conclusion

The key feature of the Sea Grant system is that the research program is constantly adjusted to present day and long-term needs of the aquaculture industry through the use of peer review and overall guidance and coordination through the National Office. This purposeful, competitive process assures the highest standards of research and development. Furthermore, the Marine Advisory Service provides the mechanism to identify research needs and to bring these research findings to user groups.

Aquaculture has the potential to reduce the tremendous trade deficit that presently exists in seafood products. New industries, new jobs, better quality seafood products and stabilization of the existing seafood industry will be the result of a continued, and hopefully expanded, Sea Grant aquaculture program. Sea Grant can take advantage of the expertise contained in the nearly 300 universities presently participating in the program to develop the technology needed to make aquaculture successful in the United States. Failure to properly exploit the potential of aquaculture will lead to even greater trade deficits and the dependency of the U.S. on other nations to provide the marine protein needed by its people. — *James P. McVey*

Enhancing Salmon Resources

Commercial fishing, once a mainstay of our nation's economy, has declined to the point where seafood imports make up one of the largest additions to our foreign trade deficit. The 200-mile extension of the U.S. Exclusive Economic Zone gave domestic fishermen access to 20 percent of the world's fish stocks. The United States, however, remains a net importer of fish and fisheries products. The reasons why are many and complex, ranging from rigid consumer preference for a limited number of species (e.g., shrimp and white-flesh fishes) to overfishing, environmental degradation, and pollution.

Seafood technology can perhaps satisfy some of the demand for more desirable species through the processing of unacceptable species into analog products (e.g., surimi shrimp and crab). Aquaculture can also add to domestic production through intensive cultivation of preferred species. Still, the long-term outlook is that most fishery products will continue to come from capture fisheries. If it is true, as a number of authorities claim, that the world's fisheries are very close to being harvested at maximum capacity, then the prospect of reducing the fishery trade deficit is not bright.

Recognizing this problem, Sea Grant has encouraged cooperative and coordinated research with state and federal agencies aimed at restoring and enhancing heavily exploited stocks. Among these, salmonid fisheries were targeted as having a high potential for success. A major Sea Grant effort was initiated in 1968 to apply the fundamental scientific principles of ecology, physiology, genetics, and epidemiology for the purpose of enhancing salmon populations.

In the 1930's, dam construction in the Pacific Northwest resulted in the inundation of spawning grounds of many salmon populations. In an attempt to mitigate these losses, federal and state governments developed a network of salmon hatcheries costing millions of dollars. The effort to rehabilitate salmon stocks never did reach preconstruction levels of abundance.

During this same period, commercial stocks of salmonid fishes (lake trout and white fish) in the Great Lakes collapsed. The cause is attributed to a combination of spawning habitat loss, pollution, overfishing, and the invasion of the parasitic sea lamprey. With the collapse of the salmonid populations, there was a virtual population explosion of two exotic planktivorous species, the rainbow smelt and, more importantly, the alewife. In the early 1960's, after lamprey control methods were developed, hatchery technology was introduced into the region in an attempt to reestablish the native lake trout. Once again, millions of federal and state dollars were spent on this mitigation effort with little success.

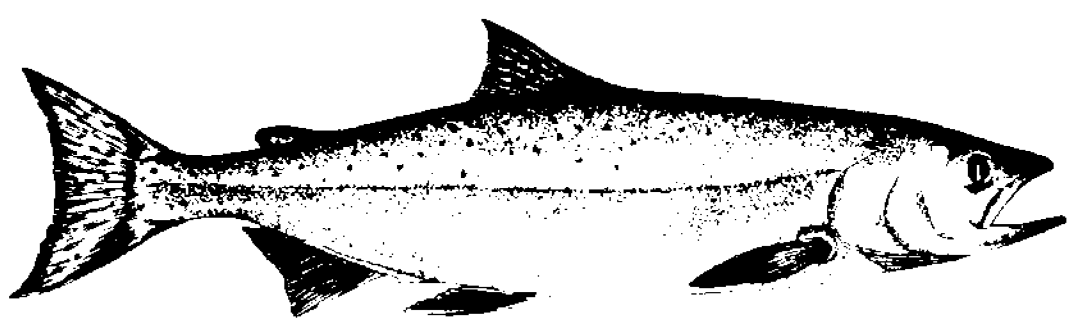
Recognizing these two seemingly unrelated yet similar problems, the Sea Grant network embarked on a multidisciplinary research and advisory program aimed at increasing the abundance of the nation's salmonid resources.

Hatcheries of the Pacific Northwest

Sea Grant's salmonid research began with a program to determine why hatchery-produced salmon were failing to return to their rivers of origin in the Pacific Northwest. Early research focused on testing the hypothesis that hatchery-reared fish were unable to detect their native river. Building on studies that showed salmon use their sense of smell to "home in" on their natal streams, Sea Grant scientists identified the principles of chemical imprinting that could be used to artificially imprint the outmigrating hatchery-raised juveniles. Artificial imprinting is presently used in hatcheries throughout the world. However, imprinting alone did not fully improve the number of returns to the fishery.

In addition to the studies on imprinting, a research program was begun on hatchery production methods with particular emphasis on smolt production (the life stage of salmon that transforms it from a freshwater into a saltwater fish). The research premise is that healthy smolts would have better than average post-release survival rates. This was supported by observations of high mortality rates among young fish introduced to saltwater before the smolt transformation had been completed.

Initial studies emphasized the development of better feeds, improved



water quality, and disease control. Later, research focused on improving growth of hatchery stocks, controlling reproduction, and determining the optimal time to release juvenile fishes from the hatcheries. These pioneering studies led to fundamental investigations on fish genetics and control of reproduction and smolitification through hormonal and environmental manipulation. The results of this long-term research have been to increase the survival of hatchery-reared fish. These developments also provided the foundations for commercial salmon sea ranching and salmon pen culture. The net effect of Sea Grant activities has been a substantial increase in the availability of Pacific salmon species, and the development of a new salmon culture industry.

Ecology of Pacific salmon

Complementing the hatchery research was research on the ecology of salmon. Studies of seaward migrating salmon showed that, for a number of important salmon populations, smolts took up residency in estuarine waters for a few months before moving out to sea. Those fish that reside in estuarine waters longer have higher survival rates. These Sea Grant results were among the first to identify the importance of Pacific Northwest estuaries as fish nursery areas. Although it has long been believed that survival of young salmon depended on the occurrence of nutrient upwelling during their first months at sea, Sea Grant researchers were the first to test this hypothesis and demonstrate that such a relationship does not exist. What these investigators did learn was that survival was highly dependent on phenomena that take place during the first two to three weeks after young salmon reach saltwater. Preliminary evidence suggests that predation at river mouths is the major source of salmon mortality.

Detailed analyses relating environmental data such as sea surface temperature, prey abundance, and fish health to salmon abundance have enabled Sea Grant scientists to develop a number of forecasting and management models. Fisheries scientists now use these models to determine how natural ocean fluxes influence the distribution, abundance, and movements of different salmon stocks and species. These models are also used by resources managers to predict the timing of adult salmon runs and to identify the most appropriate times and locations for harvesting these resources.

Introduction of salmon into the Great Lakes

While salmon research was underway on the West Coast, fisheries biologists were initiating cooperative studies with state fishery agencies to introduce Pacific salmon (coho and chinook) into the Great Lakes. Sea Grant's research on Pacific salmon was transferred directly to Sea Grant programs in the Great Lakes states. Further advances in hatchery technology and salmon physiology ultimately led to the production of chinook and coho salmon well suited to the Great Lakes environment.

The outcome of these introductions was twofold. First, two highly desirable salmonids that were very acceptable alternatives to depleted indigenous species were established in Lake Michigan. Second, salmon proved to be an effective means of controlling nuisance alewife that had spread throughout the lakes.

Rather than encouraging the development of commercial salmon fisheries in the Great Lakes, Sea Grant worked to develop high value-added recreational fisheries and organized extensive advisory efforts with the private sector, which resulted in a thriving Lake Michigan recreation salmon fishery. This success resulted in cooperative programs to introduce salmon into the other Great Lakes. Again, very valuable recreation salmon fisheries were established in each of the Great Lakes. In Lake Ontario, with no history of a recreational fishing industry, Sea Grant is credited with developing a highly successful one. Today, the Great Lakes are considered the most valuable recreational fishing areas in the world. The value of the fishery is presently estimated at approximately $2 billion annually.

As the Great Lakes salmon fisheries grew, scientists concluded that the foundation of these fisheries was the alewife forage base. Since man can stock almost any number of salmonids, the limits of the fishery are determined by availability of forage stock. However, no method existed for estimating stocking levels of salmon based on their dynamic interaction with alewife stocks.

Responding to this need, Sea Grant fishery scientists developed a mathematical model of predator-prey interactions based on the feeding and energy requirements of the set of species found in the lakes. The model is capable of estimating salmon demand on forage populations. After development, the model was widely transferred to Great Lake fishery agencies who now use it in determining annual stocking rates. Versions of the Sea Grant model have been adapted for use in many areas of the country including the Pacific Northwest and Alaska. It has also become a valuable tool to fisheries biologists studying salmon ecology.

Information transfer

Although ocean and Great Lakes salmon environments differ, many problems are similar. Hatchery production innovations developed in the Great Lakes area are quickly adopted on the coast and vice versa. Ecological hypotheses developed on the West Coast are presently tested in the more controlled environment of the Great Lakes.

The flow of technical and scientific information between the West Coast

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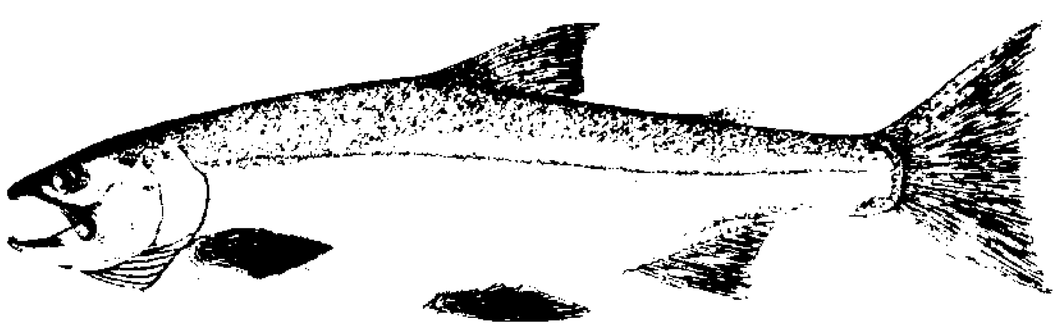
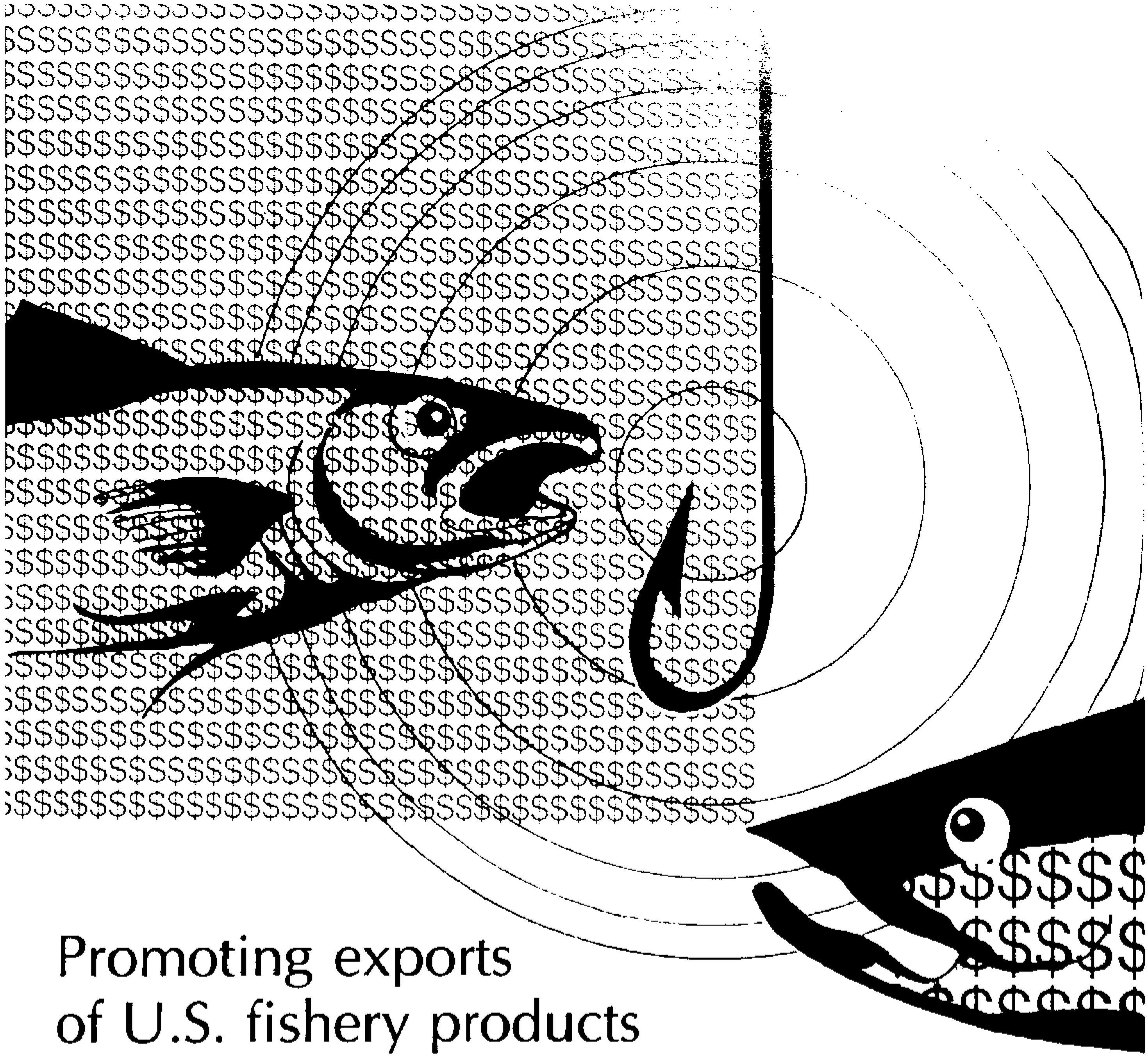




Promoting exports of U.S. fishery products

Fishery products contribute significantly to the U.S. trade deficit. In 1987, exports of all fishery products were valued at $1.7 billion, an increase of $300 million over 1986. Unfortunately, imports increased nearly $1.2 billion to $8.8 billion. This deficit of $7.1 billion caused fishery products to be among the top five commodities contributing to the overall trade deficit.

Sea Grant programs, with their research capability in aquaculture, seafood technology and fishery development, and their technology transfer component, the Marine Advisory Service (MAS), are in a unique position to help address this component of the nation's economy by assisting the seafood industry in developing overseas markets. MAS programs across the country have played a major role in identifying and enhancing foreign markets for a variety of fishery products.

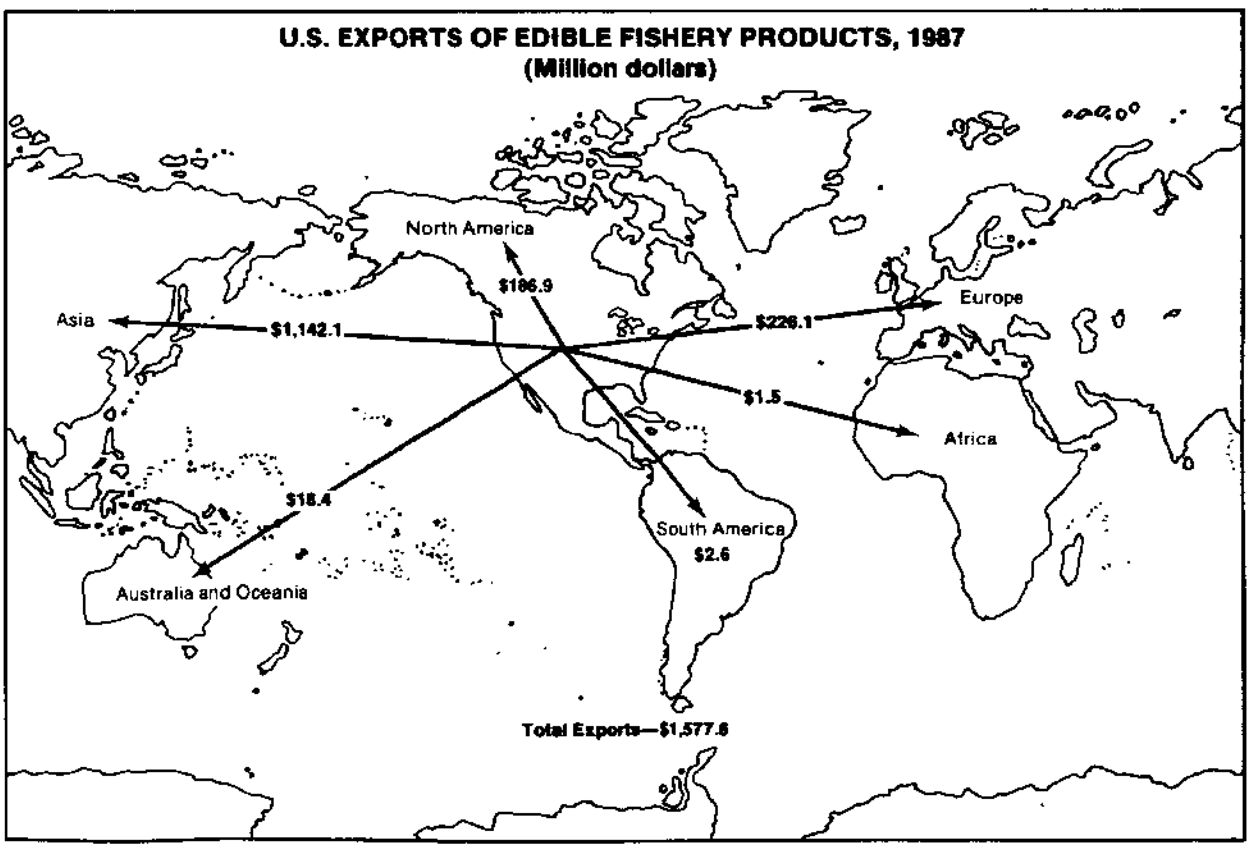
Working with Industry

The assistance provided by MAS personnel comes in a variety of forms. One form of assistance is to act as a liaison between fishermen, processors, dealers, and the major fish export firms. Another is to demonstrate new methods of harvesting species desirable for export. A third area involves the introduction of improved storage methods to provide a better quality product for U.S. companies to export.

Sea Grant MAS involvement in helping to increase the export of fisheries products dates back to the early 1970's. The University of California Sea Grant Marine Advisory Service responded to the reduction in the harvest and export of abalone by helping to develop the sea urchin fishery. Through a joint effort with the National Marine Fisheries Service (NMFS), the California program held a series of workshops to bring together fishermen and processors with representatives of Japan Airlines to discuss exporting possibilities. Next, the program developed contacts with Japanese exporters for the developing industry, and helped develop technology for extracting, packaging, and shipping high quality urchin roe. By 1987, the value of this expanding export market had grown to more than $25 million.

The MAS staff has also worked with Santa Barbara, California, fishermen to develop the sea cucumber fishery as an export product. MAS assistance provided technical information on life histories and habitats of the sea cucumber in order to identify productive fishing areas and suggest optimum levels of harvest for fishermen. Today, markets in Japan and the Philippines import sea cucumbers harvested in southern California waters.

In Rhode Island and New York, the MAS fisheries specialists have educated fishermen about the need to improve on-board quality of locally harvested fish products to gain acceptance in foreign markets. A major focus of their efforts has been to inform fishermen of various on-board refrigeration systems that will improve the quality of popular export species such as squid and butterfish. They have also assisted fishermen in developing the capability to begin exporting squid to foreign markets. A group of 25 fishermen in Montauk, New York, were brought together through the efforts of the extension service personnel and informed of



various exporting opportunities and potential markets. They formed the first fishermen's cooperative in the Northeast for the purpose of developing exports. As a result of this 10-year effort, several New England fishermen have established joint venture operations with the Japanese to export squid and butterfish. The annual value of squid and butterfish exports now fluctuates around $20 million, up from nearly zero a decade ago.

In New Jersey, Sea Grant extension personnel have actively helped the seafood industry in the state and region develop export opportunities. Beginning in March 1981, the New Jersey Extension Service and NMFS hosted the Japanese Fisheries Association and the Japan Deep Sea Trawlers Association at a fisheries workshop. Sixty-three interested fishermen participated in the workshop, which was designed to show Atlantic Coast fishermen and processors gear, methods and procedures for producing fish that would meet Japanese requirements for quality and appearance.

Following the March workshop, the Sea Grant Extension Service hosted a Japanese trade mission in Cape May County, New Jersey, in August 1981. The aim of the mission was to observe U.S. processing facilities, meet fishermen and processors who would want to develop overseas markets, and to explain the Japanese efforts in test marketing fishery products. The results of the test marketing program would then guide Japanese importers to the further development of markets for U.S. fish and fish products.

A major effort that the New Jersey Sea Grant Extension Service co-sponsored with NMFS and other New Jersey state agencies, was a Mid-Atlantic Seafood Export Conference in October 1982. The Conference attracted more than 80 individuals from eight states and the District of Columbia. The objectives of the conference were to describe the basics of exporting (e.g. financing, shipping), review market potentials (e.g. available resources, overseas markets), and provide an opportunity for industry representatives to meet and discuss future marketing efforts.

New Jersey Sea Grant personnel have also worked closely with the New Jersey Department of Commerce's Division of International Trade to identify contacts within the state's seafood industry. These contacts have been useful as New Jersey officials travel to international trade shows (France, 1984; England, 1985) to promote the state's seafood products on the international market.

The Virginia Sea Grant Marine Advisory Program has been active in supporting NMFS and regional Fishery Development Foundations in promoting the export of U.S. fish and seafood products. The advisory program has also developed a program to assist Virginia seafood producers in exploring the potentials of export markets. In 1978 and 1980, the advisory program sponsored seafood export marketing workshops for the Virginia Seafood Council. These workshops have aided Virginia seafood producers in establishing a targeted export marketing program.

In 1980, the advisory program participated in trade missions to Nigeria and the Netherlands and coordinated the shipment of seafood samples from Virginia to be exhibited at trade shows in Japan and Holland. Advisory program personnel also participated in the USDA Cairo, Egypt, Food Show. MAS coordinated the shipment of frozen seafood samples and represented regional interests at the show and during visits with Egyptian government officials and U.S. AID representatives. MAS also secured and coordinated shipment of Virginia seafood products to additional shows in Holland, Saudi Arabia and London. Several promising sales leads were developed and continue to be pursued by dealers.

A very successful export program that was initiated through the assistance of the MAS staff in Virginia initially began five years ago. With support of the Gulf and South Atlantic Fisheries Development Foundations, MAS personnel introduced, for the first time, soft shell blue crabs in the Japanese market. Two soft-shell crab suppliers from Virginia sold approximately 30,000 dozen crabs to the Japanese market in 1984. Original marketing information indicated that it was reasonable to assume that 60,000 dozen soft-shell crabs could be supplied to the Japanese from the Chesapeake Bay region within two to three years, but exports in 1987 exceeded 80,000 dozen and are limited only by the supply of these crabs.

In 1984, a Sea Grant MAS agent walking the docks in Montauk, New York, realized there were growing numbers of large sport-caught tuna being landed, but wastefully discarded. A concerted effort to educate sport fishermen and charter operators about proper handling of these large fish for potential sale and export to the Japanese sashimi market ensued. By 1987, an estimated $4 million was being returned to recreational fishing interests in the U.S. by Japanese fresh tuna buyers who now regularly ply the major recreational tuna centers along the East Coast.

Conclusion

The Sea Grant Marine Advisory Service supports and aids exporting opportunities for the United States seafood industry in a variety of ways. Many of the potential economic impacts of expansion of foreign markets have yet to be realized. Meanwhile, new foreign markets will continue to be identified and improvements in quality will continue to be made through Sea Grant research and development efforts so that economic benefits can grow. In addition, Sea Grant research and development in aquaculture and underutilized species development has and will continue to cut demand for foreign products in the United States.

While the emphasis here is on marketing, a traditional MAS function, this is just part of a major coherent Sea Grant program of research and development. For example, the urchin roe markets could not have been developed without Sea Grant-sponsored research on urchin biology and stocks, nor could the soft-shell crab industry have become such a success without pioneering Sea Grant research on crab biology and recirculating systems for shedding operations. While the deficit in fishery product exports continues to grow, it would be considerably worse without the cohesive, combined efforts of the National Sea Grant College Program. — *Bernard L. Griswold*

Marine Biotechnology

(Continued from page 9)

tance at the molecular level will advance the understanding of resistance mechanisms and provide new approaches to control of disease in both plants and animals.

Conclusion

Academic, governmental and industrial scientists and administrators in several countries, especially Japan, are taking interest in and actions to support development of marine biotechnology. Most aggressively, Japan will invest more than $200 million during the next 10 years to develop a full-scale institute of marine biotechnology. About $50 million has been allocated for the institute's construction in the second half of fiscal year 1988. The U.S.S.R. has also recently launched a major effort in research on marine natural products. Although the National Cancer Institute has increased significantly its focus on marine sources of anti-cancer substances during the past two years and the Office of Naval Research has increased its support for certain kinds of biotechnological research, no broad effort in marine biotechnological research has emerged in the U.S. However, interest continues to increase for a number of reasons, among them —

- the promising results of investment in such research so far,
- the relatively unexplored state of marine organisms and their chemical and biological capabilities and processes,
- the greater phylogenetic and species diversity of marine organisms as compared to terrestrial organisms,
- recent progress in DNA technology that shows how to exploit the biochemical capabilities of organisms quickly and efficiently,
- the opportunity to conduct research that is directly relevant both to commerce and to advancing our knowledge of fundamental processes in marine science,
- the need to reduce the dependence of the chemical industry on petroleum, and
- the need to enhance the Nation's potential for economic competitiveness in international markets.

It is clear from Sea Grant's at first tentative and then more deliberate effort in marine biotechnological research over the past few years that scientifically rewarding research can play an essential role in laying the basis for commercial development. However, many additional areas of research bearing on long-term development of marine biotechnology need to be addressed. — *David H. Attaway*

Parasitic Diseases

(Continued from page 33)

into diseased waters. This is a multidisciplinary program drawing upon genetics, hydrodynamics, and mariculture. Geneticists are evaluating the heritability of MSX resistance and estimating the consequences of the interaction between resistant and nonresistant stocks inhabiting the same body of water. Hydrodynamic models are being used to locate the most appropriate sites for stocking resistant oysters to insure that their larvae settle in desired locales. Aquaculture activities aim to provide substantial numbers of brood stock to counteract the "swamping" effect of unresistant stocks (i.e., the unresistant population is capable of producing so many larvae that these could, if not corrected, out-compete larvae of resistant species for space or as food). Studies on physiological condition and immunology, described above, provide essential information required to culture with MSX resistance. This is an ongoing, high risk effort with the potential for providing the means of restoring the Nation's historically important shellfish growing areas.

Sea Grant is also pursuing additional research in the culture of oysters aimed at overcoming parasitic disease. Projects are under way to develop transgenic (genetically manipulated) shellfish that possess increased immunities to disease. Through this type of research, Sea Grant envisions the development, in the laboratory, of genetically immune oysters and clams. Furthermore, Sea Grant scientists are evaluating non-indigenous shellfish species with respect to their disease resistance and their ability to survive and grow in areas heavily affected by MSX and dermo. Risk analyses are constantly performed to insure that these exotic species are environmentally compatible.

Information distribution

The magnitude of the MSX and dermo problems both in infected and adjacent waters has such important economic and social implications that any new information on these diseases must be distributed very quickly. This is achieved through Sea Grant's Marine Advisory Service Programs that hold workshops, and produce and distribute newsletters and brochures. Communication among scientists is facilitated by Sea Grant-sponsored symposia and technical reports. Wider distribution of scientific information uses the traditional techniques of publication in the refereed literature and presentations at professional societies.

Conclusion

The advent of parasitic diseases in shellfish has resulted in the destruction of wild and cultured fisheries worldwide. Since the early 1950's, many of the nation's most productive oyster growing areas have suffered severe losses in production of native species. Recognizing this critically important problem, Sea Grant, building on existing efforts, embarked on an innovative program to alleviate the consequences of shellfish diseases. Sea Grant research on parasite life cycles, though inconclusive, did demonstrate, for the first time, that parasitic disease could be transmitted by parasitic snails. Research activities are producing fundamental understanding of shellfish immunology and its relationship to physiological condition of susceptible animals.

Through Sea Grant's leadership, diagnostic tests have been developed which enable rapid detection of dermo and MSX, thus saving growers millions of dollars in lost harvests. Sea Grant expects to continue its research programs on introducing and evaluating disease-resistant oysters and clams into shellfish-producing waters. This research will focus on the development, through modern genetic manipulation, of immune oysters and clams and the identification of environmentally compatible exotic species tolerant of major parasites. Additional Sea Grant research will seek to develop, through biotechnology, rapid growing shellfish that can be harvested before diseases take their toll. Such research holds the promise of the eventual restoration of the nation's shellfish stocks to their historical levels of productivity.

— *Eugene S. Fritz and James P. McVey*

Enhancing Salmon Resources

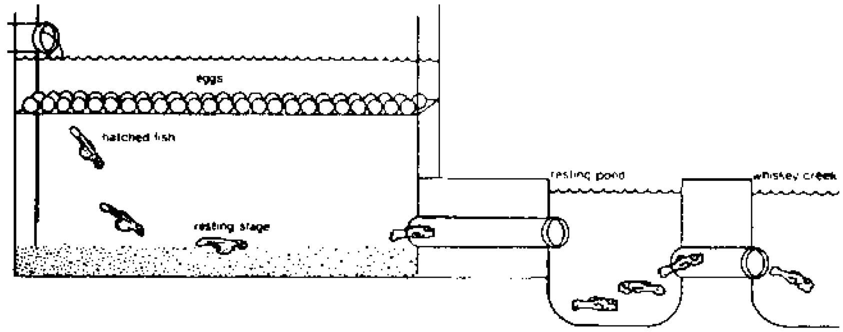
(Continued from page 39)

and Great Lakes states is facilitated by the Sea Grant communications network. Research findings are typically published in the refereed literature or as Sea Grant technical reports. The communications network targets individual Sea Grant programs that have interests in salmon research, whereas the individual program managers identify interested scientists and advisory agents in their respective programs. In this way, users are appraised of information in a fraction of the time it takes using traditional literature review techniques.

Sea Grant extension agents and scientists promote the distribution of research results through well-developed channels of communication between the Sea Grant programs and the user community. This dialog also provides a means of bringing the problems and opportunities confronting the users of the research to university scientists.

Conclusion

Sea Grant was called upon to help restore salmonid fisheries reduced by man's activities. In the Pacific Northwest, Sea Grant developed technology to improve the survivability of hatchery



produced salmon and began to identify the factors influencing survival at sea. The Sea Grant research and advisory programs ultimately resulted in the development of commercial salmon ocean ranching and pen culture as well as the development of better scientific forecasting techniques for fisheries managers. Together, these developments resulted in a substantial increase in the abundance of Pacific salmon available for the marketplace. In the Great Lakes, Sea Grant research led to the introduction of salmon species more suitable than the native species that were greatly reduced and not responding to rehabilitation programs. The introduction of salmon to the Great Lakes led to the development of a recreational fishing industry that is bringing employment and income to some of the more economically depressed areas of the nation.

Sea Grant's leadership resulted in the development of new technological innovations and methodologies used widely in the United States and throughout the world. In addition, Sea Grant trained numerous young scientists, spurred entrepreneurial development of commercial salmon ventures, and filled the scientific literature with exceptionally high quality research breakthroughs. Sea Grant's substantial effort and success in salmon research continues today with scientists developing techniques for predicting annual and long-term abundance, determining the salmon-carrying capacity of water bodies, and searching for effective management techniques that more explicitly account for the importance of physical ocean parameters in controlling the variability of salmon abundance.

— *Eugene S. Fritz*

International Trade

(Continued from page 5)

decision to cover higher animals. The University of Washington, on behalf of the Sea Grant program, applied for a patent in 1984 on the process that produces the triploid oysters. The application became a national test case. Two important questions were raised. First, under current law, could higher animals be patented; and second, whether the triploid oyster and the Sea Grant process for producing it could win protection.

The U.S. Patent Office, ruling on the oyster patent application in April 1987, established in principle the right to patent higher form animals. However, it denied a patent in this case because the resulting animal was judged not sufficiently different from a variety found, though very rarely, in nature. The principle that patents could be awarded to protect an investment in genetically-altered animal forms, however, is a crucial step in establishing the growth of commercial aquaculture. Property rights to genetically-altered fish will induce greater private sector research investment by enabling commercial firms to secure a proper share of the economic benefits that accrue to their discoveries.

Conclusion

The Sea Grant College network functions by directing the intellectual talent of the nation's universities to focus on the goal of marine resource development. The creativity inherent in the Sea Grant paradigm flows from two tenaciously held premises:

- First, technological innovation is a complex, highly uncertain process where progress comes most surely from the intellectual stimulation of confronting marine economic opportunities and societal problems with knowledge from across the many scientific disciplines.
- Second, scientific knowledge achieves its fullest measure of value when it is adopted by entrepreneurs in commercial enterprise and when it is rigidly held to the purpose of securing for the nation the benefit of its marine resources.

Sea Grant has amply demonstrated that developments achieved on the campuses can be brought to life in the marketplace. Economist Robert Solow, awarded the Nobel Prize in 1987 for his study of technology's contribution to economic growth, makes a related judgment for all industry sectors: the solution to improved technology in America is more interaction between academia and business. In the more than 25 studies on competitiveness produced since 1980 by private and public sector entities, some version of this theme can be gleaned in most, although maybe pronounced less definitively.

If the national will is committed, Sea Grant can show the way.

— *Francis M. Schuler*

(Continued from page 15)

sistant who can carry out fairly complex tasks if given explicit directions. The vehicle's computer system carries instructions for a variety of tasks such as picking up an object or tightening a bolt, but the vehicle operator must assess progress, as displayed through the sensors, and periodically adjusts the instructions to the vehicle. The issues of how often and what kinds of communications are most effective or most required are at the heart of supervisory control research. Equally important is the computer system which guides the ROV. It must be able to do some sensing of the environment and be able to learn. The offshore industry has now adopted this concept for use in ROVs, but, since the tasks these vehicles are able to perform are still relatively elementary, refinement through further research is still necessary.

Another direction for this early research was the study of the dynamics of tethers. A remotely operated vehicle may operate many hundreds of feet away from the mother ship, and the tether is subjected to forces due to the motion of the surface vessel caused by waves and to the ocean currents to which it is exposed. These forces must be accurately understood because the vehicle computers or the supervising operator must be able to compensate for them in such a way that the mission can be executed efficiently, and disasters such as the snagging of the tether on an obstacle can be avoided. Also, since it is not possible for a freely floating vehicle to accomplish mechanical work like tightening a bolt, tethers can be used intentionally as a means of anchoring. The procedures for accomplishing such tasks are not obvious and need considerable analysis.

A third direction for ROV-related research has been the development of technologies for accomplishing the various repair tasks that are considered routine on land. As an example, in the case of welding, the task is complicated not only by the remote manipulation itself, but also by the rapid quenching effects of the cold seawater. An early development by MIT researchers was an underwater stud welder that has attracted the attention of U.S. Navy repair professionals. Adaptations of this design are now being considered for ROVs.

Autonomous vehicles (AVS)

The elimination of the tether frees the submersible from drag and from the danger of entanglement, but since there is no longer a direct electronic connection, the ability to communicate is severely curtailed. The requirement for the vehicle to carry its own power source is also a formidable restriction. With regard to communication, electromagnetic waves have not proved to be a feasible technology. Acoustic communication seems to be the best possibility, but high data rates require high signal frequencies. Unfortunately, high frequencies are attenuated rapidly in the ocean. At low frequencies, sound propagation is very good, but multiple echoes corrupt the signals, and data rates are low.

Sea Grant researchers at MIT have designed an underwater acoustic telemetry system which operates in two directions, so that the submersible can send data to the mother ship, and the mother ship can send commands to the submersible. The system is reliable for distances of one to ten kilometers, and is resistant to potential errors introduced through the sonic reverberations found in shallow nearshore environments. Spread spectrum, frequency hopping techniques are incorporated to obtain data rates up to a few kilobits per second. This technology is now being adapted by at least one of the major undersea instrument manufacturers.

Generally however, AV system design assumes that there is little or no communication between the system and the operator. Prior to starting the mission, the operator instructs the vehicle about the task, and the vehicle is expected to carry it out without further assistance. The concepts of Artificial Intelligence (AI) are central to the design. At the University of Washington, for example, an AV has been developed that travels under polar ice caps, assesses information about fish and other forms of life, and returns to its mother ship. It does so while avoiding the pack ice formations and taking into account the currents it encounters while underway.

Another development by the acoustics group at MIT, working with scientists at the Woods Hole Oceanographic Institution (WHOI), is a technology for using acoustic signals to "map" the local environment of the vehicle, and simultaneously for the vehicle to locate itself within this environment, thus providing the means to navigate from one point to another. Many of the experiments to date have been simulations, but acoustic images of the *Monitor* in its watery grave off the North Carolina coast have shown the power of the technique.

The earlier studies at UNH, mentioned above, attracted the interest of the Defense Advanced Research Projects Agency (DARPA). This agency has provided funding to the university for the development of two experimental AVs with excellent maneuverability but limited depth capability. These are efficient platforms for testing early concepts such as multi-vehicle cooperation and communication.

In a related study, Sea Grant, with Navy support, examined the limitations of present technology with regard to long range operation of AVs. Three groups were involved: a team composed of investigators at MIT and WHOI; a similar team made up of investigators from Florida Atlantic University (FAU), Carnegie-Mellon University (CMU), Perry Offshore, Inc., and Harbor Branch Foundation; and a third group from Texas A&M University (TAMU) and Shenandoah Systems Company (SSC). This study showed that present technology is adequate for the long-range navigation problem and for the performance of simple tasks. (Power storage, however, is one of the serious limitations to long-range operation.) The TAMU-SSC group is now developing the AI software and control electronics, which will be installed on a research submarine for a demonstration of the AV concept.

Successful collaboration spawns other activities, and it is not possible to list all the "spinoffs" in a brief report. As one recent example, the H.A. Perry Foundation is now sponsoring a human-powered underwater vehicle contest in cooperation with faculty at

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Sea Grant will continue to focus on the needs of U.S. ocean industry

FAU. The purpose is to inspire innovative designs of vehicles in recognition of the fact that most research on submarines has concentrated on the needs of the military (high speed, low noise, etc.). The knowledge needed for the relatively slow speed maneuvering of ROVs is quite a different matter.

This kind of research is not esoteric. It requires cooperation among engineering faculty specialists, and it therefore provides a truly interdisciplinary education for the students who are associated with it. In recognition of this area's vitality and importance, industry has periodically sent their own engineers to work with Sea Grant researchers. The objective is to accelerate technology transfer and to help universities to understand the technology problems facing industry. Student graduates are much in demand, and industry has provided several of the universities with grants for student support.

Conclusion

Encouraging domestic commercial innovations through carefully designed long-range research and accompanying technology transfer is a direct objective of the National Sea Grant College Program. Long-range research can be productively carried out as a partnership among government, academia, and industry. Industry provides information concerning long-term problems relevant to international competitiveness; Sea Grant research programs are then planned, taking into account these needs. Through advisory service/technology transfer programs, industry is encouraged to adapt the fruits of the research into its product improvement.

Manpower development and improved technology are never ending demands of a healthy economy. Sea Grant will continue to focus on the needs of U.S. ocean industry. The continuing objectives of Sea Grant research in the specific area of underwater work vehicle technology are: (1) designing appropriate missions for "single purpose" vehicles to take advantage of the best of current technology and to fit within current limitations, (2) extending present power and communication limits, (3) developing advanced artificial intelligence concepts to expand the ability to learn from the environment and to better control the vehicle, and (4) learning ways to accomplish progressively more complex mechanical work functions.

— *Richard C. Kolf*

Fishing Gear Technology

(continued from page 22)

facturers have improved design and performance of their nets, and (3) fishermen in Alaska joint-venture operations have used results of the tests to stabilize their catch rates and maintain consistent landings.

Conclusion

Sea Grant is filling a national void in the area of fishing gear technology. There are no other programs currently supporting the industry in gear technology since the National Marine Fisheries Service severely cut back its activities a decade ago. The U.S. industry, facing unprecedented hi-tech competition from numerous subsidized foreign countries, is in no position to underwrite the research and development efforts needed to verify the technical and economic viability of new methods. By teaching fishermen new applications and giving them an understanding of gear behavior in changing conditions, Sea Grant Marine Advisory Service programs can help fishermen help themselves. Sea Grant maximizes their potential to compete in international markets yet respond to vagaries of biological populations and necessities of appropriate management strategies. — *Bernard L. Griswold*

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