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## Chapter 7

# **Risks and Benefits of Marine Biotechnology: Conclusions and Recommendations**

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### **1. INTRODUCTION**

Marine biotechnology already provides substantial social benefits, including improved productivity in aquaculture, new pharmaceuticals, and enhanced manufacturing with enzymes derived from marine animals, plants, and microorganisms. A broad-based industry is developing that will bring economic gains to entrepreneurs, their employees, the communities in which they establish their facilities, and indeed to the entire nation.

Expanded research and development in genetic recombination of marine organisms is leading to beneficial discoveries with wide application. A “blue” revolution in aquaculture may be on the horizon, following the model of the “green” revolution in agriculture, in which new techniques create faster-growing, more nutrient-efficient fish and shellfish to provide a source of protein for the world’s expanding human population while reducing harvest pressures on natural fisheries.

Marine biotechnology is also poised to make an important contribution in the area of bioremediation. To help reverse decades of environmental degradation in bays, estuaries, and other fragile coastal ecosystems, the techniques of modern molecular biology are being applied to enhance the capabilities of naturally occurring microorganisms that are effective metabolizers of sulphur, nitrogen, and hydrocarbons.

As with any new technology, however, all aspects of proposed applications need to be considered, including potential risks. Some risks are clearly understood and easy to manage; others may be difficult to foresee or entirely unknown. In particular, it is hard to predict the ecological consequences of introducing GEOs into marine environments. Containment of introduced organisms may be impossible, and escaped transgenic fish or bacteria may establish viable populations in the wild and alter natural ecosystems.

Other considerations are social and economic. Extended delays or overly burdensome compliance procedures will result if regulatory agencies are unprepared to provide effective and

efficient evaluations of permit applications because of a lack of basic scientific knowledge or a lack of appropriate risk assessment protocols. Oversight procedures must be designed to minimize adverse environmental effects while maximizing social and economic benefits. Moreover, the general public must have the opportunity to consider associated cultural and ethical issues before new products come to market. Unlike other high technology applications that alter society in fundamental ways—advances in computer applications, for example—biotechnology affects life processes. If adequate protections are not assured, unfounded fears of biological change may undercut commercial viability of beneficial products.

This volume explores the risks and benefits of marine biotechnology and considers appropriate policy responses. Contributors assess the level of scientific knowledge required for ecological risk assessment of genetically engineered marine organisms, propose a model for ecological analysis that takes scientific uncertainty into account, make recommendations for legislative and regulatory reform, and evaluate the economic implications of marine biotechnology. Here, the authors present a brief summary of conclusions and recommendations drawn in preceding chapters.

## **2. THE SCIENTIFIC KNOWLEDGE BASE**

Marine organisms interact with their environment in ways that are significantly different and less well understood than terrestrial species. Even though continuing research is narrowing gaps in the knowledge base, it will be more difficult to predict the nature and extent of ecological effects in the marine environment than has been the case in terrestrial applications. Introduced marine GEOs will be more difficult to contain and retrieve, and organisms that do escape containment will have wider opportunities for reproduction and dispersal. The majority of plants and animals used in agriculture that have been modified through genetic engineering are domesticated species dependent upon human mediation for survival, and the risk that they will establish viable fugitive populations and disturb natural ecosystems is limited. In contrast, genetically engineered fish, shellfish, and marine microorganisms will be more difficult to isolate from the environment once introduced and will retain their natural survival skills if they escape containment. Furthermore, the effects of an escape may not be localized. Many marine organisms utilize long distance dispersal mechanisms to establish populations in widely separated regions of the oceans.

These factors increase the uncertainty inherent in ecological risk assessment in the marine environment. Although it is unlikely that marine GEOs pose a direct threat to human health, the level of risk posed to natural ecosystems is unclear. Experience with exotic species indicates that in general there is minimal impact when organisms are introduced into novel habitats. Most organisms are adapted to their natural environment and demonstrate reduced fitness in other locations. In cases where adverse outcomes do occur, however, negative ecological and economic effects can be dramatic and widespread. In response, researchers are developing ways to modify GEOs to minimize the likelihood of adverse effects.

The need for further research in marine ecology and ecosystem function is the major obstacle to full exploitation of the benefits of marine biotechnology. At a minimum, research targeting the following issues should be accelerated: microbial ecology of aquaculture systems, interactions of transgenics with local communities and food webs, and effects of transgenic manipulation on life history traits.

Incomplete information also delays regulatory approval. Currently, risk assessors must consider proposals to develop and test marine GEOs cautiously, on a case-by-case basis. Government and industry should support increased basic research to lay the groundwork for an

approval process that would be efficient and responsive, while maintaining high standards of environmental protection.

### **3. A MODEL FOR ECOLOGICAL ANALYSIS**

In the conventional view, introduced organisms are said to have “escaped” if they are found outside the containment area or the area of uncontained introduction. To conduct an analysis of ecological effects that may be associated with marine GEOs, however, a broader definition is required. For example, if introduced GEOs utilize novel resources unavailable to the parent organisms (e.g., new prey or refugia) this represents an escape from existing ecological constraints even though the altered organisms remain within the local ecosystem. Escape must be defined to include any change in the fundamental niche of the parental strain.

As a first step in identifying ecological risk, regulators must assess the probability of escape using this broader definition. Next, they must estimate the probability that escaped GEOs will successfully establish viable, fugitive populations. Although there may be short-term effects caused by nonreproductive individuals, a higher level of scrutiny is required for organisms that are reproductive, or that have the potential to revert to reproductive status from induced sterility. Third, risk assessors must evaluate the rate at which fugitive populations may establish themselves, and, once established, spread across a habitat or among habitats. Fourth, they must determine the overall likelihood of ecological impact, given their estimates of the parameters listed above. Finally, decision makers must weigh potential risks against expected benefits.

Although ecological risk varies on a case-by-case basis, we support the following general assessment in this book: the likelihood of escape for introduced marine GEOs must be considered high; the risk that escaped organisms will establish viable populations is moderate; the rate of establishment of fugitive populations within enhanced niches is likely to be high; and the rate of spread of fugitive populations across habitats is likely to be moderate, although rapid short-term expansion is possible. In summary, we consider the over-all potential for ecological effects in marine ecosystems colonized by populations of escaped GEO to be moderate. As mentioned above, however, the level of risk can be reduced significantly if GEOs are modified to restrict their opportunities for long-term survival, reproduction, and dispersal.

### **4. LEGISLATIVE AND REGULATORY REFORM**

Legislation currently in place does not specifically address marine GEOs, and there is no clear statutory mandate for oversight of these products as they are developed for commercial applications. Presently, genetically engineered microorganisms are regulated by the Environmental Protection Agency (EPA) under authority granted by the Toxic Substances Control Act (TSCA). Food animals intended for human consumption, including marine aquacultural harvests, are regulated by the Food and Drug Administration (FDA) under authority granted by the Federal Food, Drug and Cosmetic Act (FFDCA). By default, ecological risk assessment is the responsibility of the agency with primary human health jurisdiction. As a result, EPA evaluates ecological risk for transgenic marine microorganisms, and FDA assesses ecological risk for genetically engineered fish and shellfish.

Because standardized protocols have not been established, FDA personnel oversee development of transgenic fish using guidelines promulgated in 1995 by the now-defunct Agricultural Biotechnology Research Advisory Committee (ABRAC) of the U.S. Department of Agriculture (USDA). The ABRAC documents provide a pathway of over 20 detailed flowcharts

and worksheets designed to ensure safety and security during research and development of genetically engineered aquaculture products. Potential ecological risks are also considered. In our view, the primary drawback of the ABRAC risk management methodology lies in its unnecessary specificity. There is little room for case-by-case distinctions and the use of best professional judgment. In contrast, the EPA list of points to consider and the USDA biotechnology products application documents lay out a more general framework of basic questions to be asked that allow regulators to draw from experience to determine the level of scrutiny applicable in each case.

To protect the environment—in addition to safeguarding human health and ensuring food safety—risk assessment must include input from experts in marine biotechnology, oceanography, marine ecology, and the ecological dynamics of marine fisheries. In reviewing applications to introduce GEOs into the marine environment, regulators at EPA and FDA should collaborate with personnel from outside agencies, including the National Oceanographic and Atmospheric Administration (NOAA), the Fish and Wildlife Service (FWS), the National Marine Fisheries Service (NMFS), and the National Sea Grant Program. If possible, an inter-agency oversight group should be established.

According to the Federal Coordinated Framework for the Regulation of Biotechnology, established in 1986, biotechnology products should be evaluated based on their expressed characteristics, not the tools used in their production. At present, however, regulators implicitly, and often explicitly, consider the production process, thereby applying different standards to biotechnology products than to conventional products. Furthermore, regulations and procedures vary from agency to agency. These regulatory inconsistencies, and other weaknesses in the risk assessment structure, may slow development of beneficial products and retard economic progress in the marine biotechnology industry. Although statutory clarification would be useful, Congressional action is not required. Established protocols, including the EPA Points to Consider, can be interpreted broadly enough to ensure appropriate appraisal of the risks associated with marine GEOs, provided the appropriate expertise is brought to bear. If the recommendations outlined here are implemented, including accelerated basic research and standardization of oversight procedures, policy makers and regulators will be prepared to act expeditiously; if not, unnecessary delays will occur as government agencies strive to catch up to private sector advances.

To complicate matters, non-federal government agencies also have oversight obligations. The national government has authority over U. S. territorial waters and regulates activities conducted in the Exclusive Economic Zone beyond the three-mile limit. Inside that demarcation, however, regional, state, and local agencies may exercise oversight responsibility. Federal and state agencies often do not have standardized procedures and do not cooperate efficiently. In addition, many coastal states with an interest in regulating commercial enterprises related to marine biotechnology are not prepared to undertake such supervision. The necessary statutes have not been enacted and the appropriate expertise is not available within their agencies.

Policy makers must also consider international implications. For economic reasons related to global competition, and for ecological reasons associated with the dispersal characteristics and life histories of marine organisms, adoption of multilateral agreements is an important component of any effort to manage risk comprehensively. Developed nations need to standardize responses to products of marine biotechnology, and developing nations need to maintain environmental protection even as they work to attract private investment.

## **5. ECONOMIC IMPLICATIONS**

Costs to the marine biotechnology industry associated with regulatory compliance cannot yet be estimated with accuracy. Risk assessment protocols have not been standardized, nor is it clear which offices of which agencies will exercise federal, state, and local oversight authority. Industry may have to comply separately with procedures administered by various agencies with differing agendas, levels of expertise, and institutional cultures. As a result, estimates of compliance costs range across a wide spectrum.

If regulations are appropriately applied, however, costs to industry may not be exorbitant. The potential for direct impact on human health and food safety from biotechnology-based marine aquaculture or bioremediation is small. As a result, marine biotechnology companies should not have to meet costs presently borne, for example, by firms attempting to introduce new pesticides or food additives. Satisfying regulatory requirements for these products can require expenditures in the millions of dollars; extensive toxicological studies using animal models are often necessary. In contrast, the cost of ascertaining that transgenic fish and shellfish are safe for human consumption, and receiving agency approval for production and marketing based on these criteria, may have associated costs that are relatively modest.

Industry may find that significantly larger outlays are required to bolster the inadequate science base presently available to regulators attempting to estimate ecological risk. Private companies, particularly those first in line with products requiring approval, may find it necessary to fund their own research in marine ecology and the effects of genetic manipulation on morphology, life history, and fitness to provide data to support their applications. This may pose a substantial burden. The costs of supporting such studies can be high both in terms of time and money. A single project, targeting a limited question, may take a year or more to complete and may require an investment of several hundred thousand dollars. Many such studies are needed. When added to in-house research and development costs, and the outlays for public relations and advertising that marketing such products to a wary public will demand, it is clear that private development of marine biotechnology products is a capital intensive undertaking. Potential profit margins may be such that additional costs associated with conducting large-scale basic research would be an insupportable burden. In addition, industry is concerned with the appearance of conflict of interest in studies funded by companies with an economic stake in the results.

This logic underscores the importance of increasing government-sponsored research. The investment in public funds will pay dividends as beneficial products come to market and the marine biotechnology industry contributes to international economic competitiveness. If an appropriate regulatory framework is established, supported by adequate scientific data, compliance costs to industry will be manageable, the environment will be protected, and the nation will reap substantial social and economic benefits.

## **6. THE FUTURE OF MARINE BIOTECHNOLOGY**

The first successful gene transfer in fish occurred in 1986. Scientists isolated the segment of DNA that codes for expression of growth hormone production in rainbow trout and transferred it into the common carp. The result was a fish that grew up to 40% faster and reached a larger size than its unaltered siblings. That same year the first agricultural biotechnology product was field-tested. Researchers demonstrated that the so-called “ice-minus” bacteria could perform the task for which they were designed—to retard the formation of frost on strawberry plants.

Since that time, firms have brought many pharmaceutical and agricultural biotechnology products to market. *E. coli* bacteria now produce human insulin, and cabbage looper

*(Trichoplusia ni)* larvae manufacture interleukin-2. In agriculture, farmers plant herbicide-resistant cotton and corn, and raise livestock, including cattle and pigs, with enhanced milk production and meat quality.

Until recently, marine biotechnology has progressed more slowly. Now the pace is accelerating as industry prepares a new generation of applications for use in marine aquaculture and bioremediation. Policy makers can encourage growth in this emerging industry, and speed the development of beneficial, environmentally safe products, by reforming oversight procedures and investing in basic research to realize the dual goal of economic growth and environmental protection.