Oyster Research and Restoration in U.S. Coastal Waters

Research Priorities and Strategies

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Oyster Research and Restoration in U.S. Coastal Waters: Research Priorities and Strategies

Oysters in U.S. coastal waters have been subjected to diverse stresses that in some regions have impacted population sustainability and even survivability. While natural climatic, overfishing, habitat loss and pollution have all had great impacts, disease has become one of the most intractable problems — this is especially so in the mid-Atlantic where parasites have devastated the once-flourishing oyster industry and disabled key ecological functions that oysters play in estuarine systems.

Over the past 14 years, the NOAA National Sea Grant program has made a substantial commitment to research focused on combating the impacts of oyster disease in the major producing areas in the United States and ensuring the safety of public health in oyster consumption. Two targeted programs, the Oyster Disease Research Program (ODRP) and the Gulf Oyster Industry Program (GOIP), have advanced our scientific understanding of oyster disease and have made measurable progress in helping to develop techniques that commercial growers and resource managers have been applying in the field.

The ultimate goal of disease research is to help support successful restoration of valuable ecological services that oysters provide and rebuilding of vigorous oyster industries. Achieving these goals is no easy matter — while there are related concerns throughout the nation's oyster producing regions, each region must grapple with unique concerns with respect to disease, restoration and commercial fisheries.

Despite the many research advances, difficulties still remain in trying to restore sustainable native populations in the mid-Atlantic and cultured oysters that can be cost-effectively farmed. On the west coast, the largely-successful cultured oyster industry continues to battle mysterious pathogens that have caused large and unpredictable summer mortalities.

To critically assess the effectiveness of the ODRP and GOIP to date and to clearly define research needs to meet the goals of restoration and fisheries enhancement, the NOAA National Sea Grant Program, in cooperation with the Maryland and Virginia Sea Grant programs, brought together scientists, resource managers, industry representatives and others from across the nation in Annapolis, Maryland, in September 2003. After a series of expert presentations on research findings, the state of oyster populations in the nation's major

Photos, top to bottom:
Pacific oyster, Crassostrea gigas
Asian (Suminoe) oyster, Crassostrea ariakensis
Eastern oyster, Crassostrea virginica
Photos courtesy Virginia Institute of Marine Science

growing areas, and the status of the industry in these areas, participants broke into five workgroups. Their goal was to develop and prioritize key research objectives in these areas: (1) Oyster Fisheries Management and Restoration, (2) Genetics and Oyster Populations, (3) Disease Research, (4) Aquaculture and Hatcheries and (5) Public Health and Processing.

Research Priorities

In detailing specific research needs, a number of common principles emerged across all workgroups and included the following:

- ***Partnerships.*** Efforts must be made both within NOAA and across federal, state and local agencies to better coordinate all aspects of oyster research for commercial aquaculture, ecological restoration and ensuring shellfish health. Collaborative studies among researchers in the U.S. and, where applicable, internationally, will continue to prove invaluable as will cooperative testing of oyster stocks under a variety of environmental conditions.
- ***Infrastructure.*** A concerted effort and investment is needed to develop and support infrastructure needed to maintain a diversity of oyster broodstocks required for long-term development, field-testing and implementation of disease resistant strains. A number of different models for the necessary infrastructure currently exist and efforts should be made to evaluate what would best serve regional and national interests in this regard.
- ***Standard operating procedures.*** Of particular importance are efforts to integrate research and restoration efforts in a way that leverages their respective contributions and leads to better, more insightful efforts to sustain and restore oyster fisheries.
- ***Communications among researchers is critical as is outreach education to stakeholder interests.*** Tied to the need for a web-based clearinghouse of research projects and their findings

National Oyster Disease Research Program (ODRP)

ODRP began with a Congressional mandate in 1990 after disease was identified as a major factor in the decline of the mid-Atlantic oyster industry. Other coastal regions in the U.S., including the Gulf Coast and the Pacific Coast, were also experiencing significant oyster mortalities. To assist resource managers and oyster fisheries, ODRP research has focused on the following array of disease issues:

- Optimum strategies for managing around diseases;
- Understanding the processes of parasitic infection;
- Improved understanding of the oyster's immune system;
- Hatchery techniques for producing disease-resistant strains;
- Molecular tools to better monitor the onset and presence of disease.

To date, some $20 million has been invested on research; among the achievements have been:

- Development of new tools for disease diagnosis;
- Successful breeding and culture of disease resistant oyster strains;
- Development of new models on the interaction of disease and environmental factors;
- Development of a new understanding of the disease process at the cellular level; and
- Identification of several strains of known diseases and new species of shellfish parasites.

Gulf Oyster Industry Initiative (GOIP)

GOIP was created in 1999 as a result of efforts by the Gulf Oyster Industry Council, a cross-section of

Gulf oyster industry leaders, state resource managers and academic researchers. Congressional support identified several key areas of research:

- Human pathogenic organisms;
- Consumer attitudes;
- Oyster diseases;
- Coastal restoration and freshwater diversions;
- Labor and mechanization in the oyster industry;
- Genetics and oyster hatchery technology;
- Harmful algal blooms and water pollution issues.

About $4 million has been invested on these issues — among the program's achievements are:

- Rapid detection and quantification of human pathogens in oysters;
- New post-harvest treatments and evaluation of those treatments to help assure public health;
- Increased understanding of harmful algal species; and
- An increased public education program targeted at immune compromised individuals to help reduce human health risks.

Chesapeake Bay Virginia National Estuarine Research Reserve. Planting oysters grown on floats at York River State Park, June 2000. This was done in conjunction with a Rotary Club Conference.

Photo courtesy NOAA National Estuarine Research Reserve Collection

is a source of information on restoration and related plantings that can provide important environmental as well as disease data, monitoring and evaluation results.

Priority Research Objectives

Oyster Fisheries Management and Restoration

In managing oyster fisheries, conflicting issues must often be taken into account, from the impacts of environmental change on oyster populations to social, political and legal considerations on policy-making. To promote effective regulatory policy for sustainable restoration, long-term research and development will be essential; this is especially so for large-scale environmental engineering projects that aim at releasing hatchery-bred oyster broodstock that can survive major diseases — these include MSX and Dermo in the mid-Atlantic, Juvenile Oyster Disease in the Northeast and summer mortality in the Northwest. The workgroup agreed that time is a critical factor, particularly in the mid-Atlantic where the fishery has virtually collapsed. Consequently, research goals must continue to be linked with practical applications and targeted educational outreach. Results must be translated into benefits in real economic terms that the public can better appreciate. Workshop participants emphasized the regional differences in oyster-producing states: the Northwest is primarily a hatchery-based aquaculture industry that relies on leased grounds; the Northeast is largely a leased-bed aquaculture industry that relies on oysters from the wild as well as, in some areas, hatchery-reared oysters for grow out; the Gulf includes both a public harvest and leased bottom industry; and the Chesapeake Bay and east coast states have public and leased grounds. Despite these differences, there are commonalities as well, which a national research agenda must take into account. To develop the science-based knowledge that will be necessary for managing and restoring oyster resources, the following are critical: (1) better

surviving oyster populations, (2) improved management strategies, (3) enhanced restoration efforts, and (4) development and application of clear evaluation criteria. Towards these ends, the workgroup prioritized the following research goals.

- Intensify the current breeding program of disease-resistant oysters to expedite identification of regionally relevant oyster strain(s), while field testing the end products in large-scale resource restoration. Field testing should be scaled for rebuilding oyster resources under defined spatial and temporal conditions.

1925 oyster beds on flats in Georgia. Paul Galtsoff photo, courtesy NOAA Image Library

- Initiate hypothesis-driven studies that support sustainable use of the oyster resource. Such studies include, but are not limited to the following.
  - o Examining how best management practices (BMP) vary in support of fisheries
  - o Developing scaled population biology models.
  - o Assessing sanctuaries and/or reserves for broodstock protection, ecological function and fishery enhancement.
  - o Conducting manipulation studies to understand processes that optimize quantifiable restoration goals (from landscape through smaller scales of structure).
  - o Conducting manipulative studies that focus on adaptive management.

- Evaluate oyster restoration and habitat reconditioning techniques. Such studies include but are not limited to the following.
  - o Assessing placement and quantity of cultch, seed and broodstock in relation to estuarine type.
  - o Evaluating reef and bed configurations.
  - o Conducting long-term descriptive monitoring in order to evaluate restoration performance in terms of oyster population enhancement, ecosystem function and/or water quality improvement.
  - o Determining basin level hydrographic features as habitat descriptors and determinants of basin suitability for restoration/ landscape ecology methods.

- Evaluate survival of non-native oyster species (on a regional basis as required) in relation to disease.

- Establish ecological and economic value for ecosystem services provided by oyster populations, for example, habitat value and water quality value.

Genetics and Oyster Populations

In breeding oysters for resistance to disease, it is important to recognize that selected strains that are viable for commercial aquaculture — for instance, oysters that will survive disease long enough to reach market size — will not necessarily be sufficient for ecological restoration. Restoration requires oysters that can live long enough to produce progeny that are also resistant to disease. In addition, it is important to recognize that disease-resistant strains will vary in performance from one geographical region to another because of differences in a host of environmental factors. With these considerations in mind, the workgroup participants agreed that a high priority of a comprehensive oyster breeding program is the use of quantitative methods so that comparisons can be made among strains and their performance in different geographical areas. While survival must be

well documented for evaluating restoration projects, so too must recruitment, which will require continuing development of reliable biomarkers to ensure the accuracy of such evaluations. The participants also pointed out the need for laboratory repositories that are large enough to rear, maintain and perpetuate selected lines of oysters. Given these issues, the workgroup prioritized the follow research needs.

- Ensure that the selective breeding program for producing the right oyster(s) for aquaculture and restoration employ established quantitative genetic methods.
  - o Having rearing facilities for large numbers of experimental groups (families or selected populations).
  - o Having disease-free areas or facilities for maintaining susceptible control lines.
  - o Having an ability to conduct controlled disease challenges.
  - o Having a broodstock repository for perpetuation of selected strains and/or geographical stocks.
  - o Characterizing genetic variation available for selection on disease resistance or proxy

Oyster shucking house near Appalachicola, Florida, early 20th Century. Photo courtesy NOAA Image Library

Regional impacts from targeted applied research

Research over this past decade – particularly research from ODRP and GOIP – has considerably advanced our scientific understanding of oyster disease and helped chart techniques that commercial growers, resource managers and citizens groups have applied in the field. Examples include:

- ***Mid-Atlantic:*** Researchers have made measurable progress in breeding oysters that to some extent can tolerate the pressures of Dermo and MSX diseases.
- ***Northeast:*** Scientists and resource managers working with growers have developed techniques to manage around Juvenile Oyster Disease, a disease claiming many young hatchery-bred oysters.
- ***Gulf:*** Partnerships among scientists, food technologists and industry operators have been developing a suite of new techniques to ensure healthy oyster products.
- ***West coast***: Collaborative projects are assessing the impacts of multiple stressors, including as-yet-unidentified pathogens, in the area's large and unpredictable summer oyster mortalities.
- ***Chesapeake Bay and other coastal areas:*** Several federal and state agencies, private foundations, and citizens groups have invested significantly in programs to rebuild oyster reefs, monitor oyster recruitment and survival on restored reefs, promote oyster gardening by waterfront owners, and create management programs for increasing oyster populations.

traits. Among the parameters of interest are (1) additive and non-additive components of genetic variance that are needed to predict the response to selection for a given trait and design of optimal breeding plans; (2) genotype by environment interaction that are needed to design breeding schemes for producing region- or habitat-specific selected strains; (3) genetic correlations among traits that are needed to design effective breeding schemes for improving multiple traits such as dual disease resistance; (4) germ plasm diversity in natural stocks and selected strains.

- o Mapping of disease resistance genes and quantitative trait lock (QTL) for use in marker-assisted selection and introgression programs, and ultimately for functional characterization of genes involved in disease resistance.

- Develop alternative methods for evaluating disease resistance to allow selection earlier in the life cycle. (Such physiological and biochemical markers may emerge from ongoing work by researchers.)
- Ensure the documentation of survival and recruitment of planted oysters used in the evaluation of restoration projects. Such documentation will require the following.
  - o Continuing development of markers and methods to allow higher resolution and high-throughput screening of thousands of individuals, including the characterization of the genetic composition of populations in target restoration areas, with regular updates to account for natural and anthropogenic changes.
  - o Determining the efficacy of various genetic strains, stocks and mixtures in multiple restoration projects across varying environments. This will include both focused introductions of selected strains such as CROSSBreeds and DEBYs and seeding incubator reefs in retentive areas with genetically diverse material that allows natural selection to generate adapted genotypes.
- Monitor the genetic impacts of enhancement on the genetic composition of resident populations.

Oyster Disease

Parasitic oyster diseases remain the key limiting factors in oyster restoration and commercial aquaculture on the east coast, while in the Northwest an unknown pathogen or pathogens have been responsible for oyster mortalities during the summer. The disease research workgroup focused on the goal of producing oysters that can live long enough to generate self-sustaining populations in the wild. Approximately 100 oysters per square meter are required to sustain a population — actual populations on oyster bars in the mid-Atlantic are far below this requirement. The reasons are many — from long years of overfishing and habitat destruction to pollution and sedimentation of oyster reefs, many of which were already reduced in vertical height from human and natural impacts; however, in the last 30 to 40 years, the impact of oyster diseases, especially MSX and Dermo in the Chesapeake and Delaware bays, has exacerbated oyster losses. Harvests in the Chesapeake (one measure of the state of the oyster fishery) are at less than one percent of what they were a century ago. In assessing the research needs for breeding disease-resistant oysters for aquaculture and ecological restoration, the workgroup identified the following priority areas.

- Examine variability in oyster stocks, strains and species for resistance to mortality and their relationships to defense factors.
- Elucidate the life history and biology of key oyster pathogens, in particular, MSX (life cycle and culturing), JOD (physiological and environmental influences), the Herpes virus and *Microcytos mackini*.
- Assess emerging and potential oyster diseases. This includes but is not limited to the following.
  - o Examining innovative methods for the detection of viruses.

- Evaluating the risks of introduced diseases, for example, by *C. ariakensis*, and the susceptibility of *C. ariakensis* to local diseases.

■ Determine differences in pathogen virulence for wild and cultured oysters. This will involve the following.

- Developing methods for in vivo and in vitro challenges.
- Assessing the distribution of virulent strains.
- Evaluating the variability among different oyster stocks.
- Determining the physiological mechanisms and genetic basis for virulence.
- Determining the influence of environmental factors on virulence.

■ Elucidate the physiochemical factors that influence oyster mortality. These include the following.

- Determining anthropogenic influences such as contaminants, sediments and nutrients.
- Assessing the impacts of climate change, for example, warmer waters, sea level rise.
- Constructing forecasting models based on environmental variables.

Oyster restoration efforts on the Chesapeake Bay's Eastern Shore. Photo courtesy Virginia Institute of Marine Science

Hatcheries and Aquaculture

Workgroup participants agreed that applied hatchery research is critical for developing oyster resources in the United States for private and public aquaculture — in assessing priority research goals, it is important to distinguish between developing viable oyster strains to serve the commercial aquaculture industry and developing sustainable strains to serve ecological restoration. For example, if oyster strains were bred for fast growth and disease tolerance so that they could be reliably brought to harvest in three years, that could well satisfy commercial growers; those same strains, however, would not necessarily be sufficient for ecological restoration and/or a sustainable wild fishery. Participants also pointed out the need to recognize regional differences in setting research priorities — for instance, because hatcheries on the west coast are commercially viable and critical to the success of the oyster industry, their needs will differ from those in the mid-Atlantic where hatcheries are currently employed primarily as a means for developing and evaluating disease-resistant stocks and strains for use in private aquaculture and for research on managing around disease. Recognizing these differences, the participants divided research priorities among the needs for hatcheries, nurseries and oyster growout.

Hatcheries

■ Explore water quality issues that will reduce the impact of oyster pathogens.

■ Assess methods for managing infectious diseases.

■ Determine the sources of diseases in hatcheries, including transmission from broodstock.

■ Explore the use of probiotics in hatcheries and nurseries.

■ Develop hatchery-based diagnostics for screening disease-resistant strains of larvae.

■ Assess ploidy for enhancing disease resistance.

■ Determine the use and impact of cryopreservation of eggs and sperm.

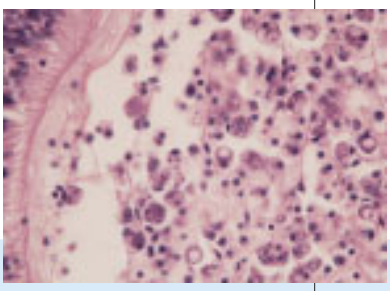
Nurseries

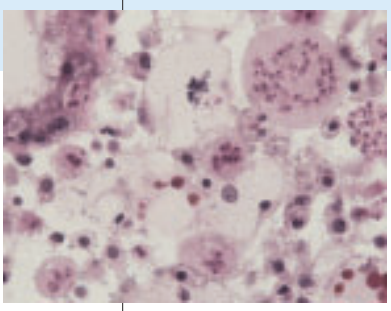
■ Assess siting, protocols and timing to avoid impact of oyster diseases and improve oyster survivability and growth rate.

- Develop tools for forecasting disease outbreaks.
- Develop cost-effective tools for rapid disease assays for field use (e.g., 1-2 day turnaround, less than $150 for each analysis).

Growout

- Continue emphasis on oyster strain evaluation under different environmental and culture conditions.
- Evaluate alternative methods of culture for growout.
- Develop risk assessment techniques for disease transmissibility.
- Improve interstate coordination of shellfish movement.
- Determine methods for decontaminating oysters with disease.
- Develop programs and initiatives to promote and facilitate the increased quality of oysters.





Top to bottom: Dermo disease (Perkinsus marinus); MSX disease (Haplosporidium nelsoni); diseased oyster at left compared to healthy oyster. Photos courtesy Virginia Institute of Marine Science.

Public Health and Processing

A principal concern with oysters harvested from warm waters is the presence of *Vibrio vulnificus* and the consequent implications for at-risk consumers. This concern is one reason that the Gulf Oyster Industry Program has supported targeted research on consumer education, post-harvest treatment and related efforts to ensure that consumption of oysters is safe.

During the 2003 National Shellfisheries Association meeting, the GOIP held a program review to prioritize major goals related to the Gulf oyster industry. Based in part on the findings of that meeting, the workgroup agreed that the goal should be to minimize public health and processing obstacles so that there will be an economic incentive for public and private investment to increase oyster production.

While the priority goals the participants developed are important for the Gulf oyster industry, they also have strong applicability to other oyster-producing regions in the U.S.

- Develop and evaluate Post-Harvest Treatment processes and educational outreach programs. These include but are not limited to the following.

  o Providing post-harvest treatment product in demonstration projects to wholesalers and retailers.

  o Conducting economic analyses regarding the changes to current handling and processing practices.

- Develop a suite of capabilities for ensuring that harmful algal blooms present no threat to public health in the consumption of oysters. These include but are not limited to the following.

  oDeveloping methods for rapid detection of toxic marine algae.

  o Conducting harmful algal bloom (HAB) research, advisory and outreach activities.

  o Conducting workshops for state and federal shellfish managers, sanitation personnel and researchers to include new monitoring, diagnostic and management protocols for use in the reopening of shellfish

growing waters closed down because of harmful algal blooms.

- Develop, implement and/or evaluate *Vibrio vulnificus* education programs aimed at informing at-risk consumer foundations and associations, pharmacies, alcohol treatment centers, shellfish consumers, the media and others.
- Develop new means for treating oysters to eliminate human pathogens. This includes but is not limited to the following.
  - o Developing or investigating new technology such as ionized water for depurating oysters of human pathogens
- Reinitiate the national indicator study.
- Address *Vibrio parahaemolyticus* research needs identified by the ISSC, recognizing regional differences in *V. parahaemolyticus* actions plans.
- Investigate post-harvest treatment and relaying techniques to manage the public health risk of harmful algal bloom impacted shellfish.
- Investigate the public health relevance of chemically treated structures on molluscan shellfish aquaculture, for instance, oysters grown off private piers.
- Foster study on using environmentally effective container-relaying as a post-harvest treatment of shellfish.
- Support remote sensing research for identification of pollution sources

Summary

Over the course of this workshop scientists and managers worked collaboratively to develop strategic research priorities that address key issues in oyster fisheries and restoration. Through plenary talks and facilitated workgroups, they explored five core areas: disease, genetics and oyster populations, oyster fisheries management and restoration, hatcheries and aquaculture, and public health and processing. From these efforts they detailed important research recommendations. In addition, a set of clear overarching themes emerged including the need for coordinated investments in research and infrastructure to support essential breeding programs, stronger fisheries research and models, better linkages between research and restoration programs and enhanced communication across the research, restoration and management communities.

Recognizing that the U.S. oyster industry is geographically and structurally diverse, it is clear that NOAA's investment in oyster research and restoration must continue to address a hierarchy of needs. Commitment to funding a diverse research portfolio will assure the strong foundation needed to manage and restore this vital resource.

A complete summary of workshop activities as well as a searchable database of research funded through the ODRP and GOIP is available at

http://www.mdsg.umd.edu/oysters/workshop/summary.html