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The commercial importance of Crassostrea *virginica* has stimulated much research into its biology and management in North America. This report reviews the extensive documentation of this research and delineates areas of uncertain knowledge which require further study. In addition, the history of oyster management in Maryland is reviewed and instructive lessons are drawn from earlier experiences.

In this review, we do not wish to separate research insights from management requirements, even though the framework of the report includes separate sections on oyster biology and on management. We are convinced that the best management of any natural resource occurs when there is linkage between gathering of information by field or laboratory study and subsequent application of this information in resource management. Optimal management depends upon thorough understanding of the biology of the resource. It also requires a supportive socio-political structure that leaves management to a skilled and informed group of managers insulated from well-meaning but uninformed political interference.

The efficient management of oyster resources can be likened to dryland farming, where it is vital to know the land and its carrying capacity, the kinds and quality of nutrients available and the best areas for supporting different agricultural crops. With regard to the crop, knowledge of nutrient requirements, productivity and growth rates, environmental requirements and tolerances, reproductive capacity, disease susceptibilities, and response to genetic manipulations is indispensible. Proper methods of cultivation, harvesting, and marketing must be determined. Long term goals must not be sacrificed for short-term ephemeral gains. Productive farms are the result of informed management; the same approach must apply to public and private management of oyster resources.

Status of Our Understanding of Oyster Biology

Concerning oyster biology, responses to environmental factors such as temperature, salinity, sediments, and dissolved oxygen have been measured to a degree that allows reasonable understanding. While the core of information nec-

Watermen on a skipjack cull through their catch, throwing back undersized oysters, empty shell and spat-holding shell, a conservation measure that provides cultch and stock for future harvests.

essary for merely adequate management exists, improved management requires answers to numerous intriguing questions. We know that C. virginica is a very tolerant animal, possessing broad resistance to a variety of environmental stresses. This is generally true of estuarine animals, which face stress from summer heat and winter cold in their relatively shallow habitat, from constantly varying (tidally and seasonally) salinity levels, and from sediments that are readily suspended by wind activity. We believe that the eastern oyster is ecologically resilient. An example of this resilience is evident in the excellent level of spat settlement in certain areas of Chesapeake Bay in 1980. This occurred after some years of poor spat settlement Bay-wide, and under conditions of relatively low quantities of oysters because of over-harvesting. However, while the oyster resource was able to respond to suitable (but unknown) environmental conditions, the fact is that even the most resilient organism has its "breaking point." We do not know how much more resilient C. virginica is, nor how much more stress it can tolerate. Thus, efforts for rehabilitation must continue.

There is need for a more thorough understanding of five major areas of oyster biology:

1. *Larval Biology.* The biology, ecology and behavior of oyster larvae are poorly understood. Their small size and the difficulties of sampling field populations continually and accurately are primarily responsible for this. We need to understand larval dispersal patterns, i.e. how far a brood drifts from its parental stock; the influence of water movements, salinity changes, temperature, light and pressure on larval behavior in the water column; factors concentrating or dispersing larvae; factors influencing settlement either positively or negatively; the relationship of larval abundance to settlement success; whether the absence of suitable cultch is a limiting factor in settlement in some areas of Chesapeake Bay; larval food requirements and whether these are being met; the impact of predators, parasites and disease on larval abundances and ultimately on settlement success.

2. *Feeding and Nutrition*. The natural food supply and nutritional requirements of all life history stages of Chesapeake Bay oysters need to be determined. Have there been changes in natural food species in the Bay over time, similar to changes in submerged aquatic vegetation? Have conditions favored less nutritious or less acceptable species at the expense of suitable food species? If there have been such changes, are they influencing gametogenesis and larval vigor? Are the variations in suitability of different areas of the Bay for settlement or growth related to differences in food quality or quantity?

   With regard to hatchery culture, more research into suitable food species for a lower salinity environment such as central Chesapeake Bay appears to be needed. Cheap and nutritionally dependable food material such as micro-encapsulated diets that can be stored and delivered in optimal quantity needs to be developed.

3. *Genetics.* Our understanding of oyster genetics is primitive compared with our knowledge of domestic animals and plants. Selective breeding of oysters is an infant science. For aquacultural purposes in Chesapeake Bay, what trait or traits need to be selected? Are there interactions between traits such that improvements in one (e.g., shell growth) result in loss in another (e.g., meat yield)? How much of an improvement over natural selection can we expect to attain by experimental selection for desirable traits and how much will it cost in terms of time, energy, space and money? How responsive are oysters to genetic manipulation? Do positive results in selecting for a desirable trait in larvae (e.g., in terms of rapid growth) persist in later life?

4. *Disease.* The role of disease in the ecology of oysters and the impact of non-catastrophic disease on population levels and environmental resistance need to be investigated. Interactions of certain diseases and methods of disease transmittal need to be established. Larval diseases, both in the hatchery and in the field, have not been studied to any extent.

5. *Pollutants.* Because estuaries are semi-enclosed bodies of water which are generally (a) shallow, (b) subject to surface runoff, (c) used as transportation arteries, and (d) in close proximity to high concentrations of people, they are particularly exposed to pollution. In many parts of the world, they are terminal sewers. Pollutants tend to be concentrated in estuaries, either by estuarine circulation systems or by adsorption onto sediments. Thus, quantities of anthropogenic chemicals, among them chlorine compounds, heavy metals, and petrochemicals, may come into contact with oysters. The influences of these materials on all life history stages of C. virginica remain to be evaluated. In addition to direct effects on oysters, we need to know the influence of pollutants on the food species of larval and settled oysters, and on contamination of the settlement substrate. Synergistic effects of various pollutants have not been studied to any extent.

Management and Rehabilitation

Improved management and rehabilitation of the oyster fishery requires thorough study of the following:

1. *Brood Stock.* What is the abundance of natural brood stock now available in different areas of the Bay? Is it increasing or declining? Is there an optimal brood stock concentration that ensures adequate spawning? Is population age distribution a factor in determining this optimal concentration, i.e., does one age group contribute more gametes than another age group?

2. *Cultch and Seed Supply.* The supply of seed oysters is a limiting and critical factor in rehabilitation and management. Those areas of the Bay consistently producing adequate quantities of seed should be pro-

tected and expanded. A private oyster farming industry would encourage growth of a seed industry.

Numerous informed observers have stated that fresh shell should not be exported or used for anything other than for replenishment of the bottom. How much cultch is now available in the Bay, and how much is optimal? What are the best concentrations on different bottom types or in different locations? Can any area of the Bay be made into a good seed area, given suitable firm bottom and adequate cultch for settlement?

3. *Growing and Setting Areas.* The best areas still available for settlement and growth need to be determined and protected. It is not clear why some areas are conducive to setting but are not suitable for rapid growth and fattening, and vice versa, but the reasons must be clearly understood in order to utilize areas effectively. The development of good seed and good growing areas depends upon a clear understanding of the environment and on the biological responses of oysters to the environment.

HistoricaI Roots of Declining Yield

While tracing the historical decline of the Maryland oyster fishery, we discovered that factors other than environmental ones have had a major impact on this decline. Throughout the past century, four dominant themes recur:

1. The decline of the fishery is predominantly a result of overfishing and ineffectual conservation efforts.

2. It is important to emphasize the need to conserve the available shell stock as cultch, to protect spat and encourage their best growth, and to expand and protect natural seed areas.

3. Private oyster culture should be encouraged because it should have the stimulating effect it has had elsewhere. It should help revitalize the industry and increase yield with increased economic benefit to all involved.

4. Political considerations, rather than limited biological knowledge, have frequently been the cause of fishery declines elsewhere. In Chesapeake Bay, efforts to improve the industry by preventing overfishing, implementing shell planting efforts, enforcing cull laws and encouraging private oyster farming have been hampered by resistance from watermen and their political representatives.

As early as 1882, the Oyster Commission headed by W. K. Brooks recommended an expansion of the private oyster culture system. Rental of oyster beds has been strongly supported by researchers and some resource managers over the last hundred years. However, strong opposition from watermen's groups and their representatives has blocked any expansion of the current small leasing program.

To help alleviate the fear of private culture, economic studies and suitable marketing strategies need to be developed. If prices were moderate and competitive with other meat sources, would market demand expand? Can the small entrepreneur be protected from the interests of large businesses?

We are now entering into the second century of informed insight into oyster biology in Maryland, since the Oyster Commission was formed in 1880. One hundred years of biological research have passed with much of this research funded erratically and poorly. We know enough to manage the resource as hunters, but not as farmers. Yet, after 100 years of continued decline of the Maryland resource, resistance to appropriate management strategies continues. The catch has declined from 10 to 15 million bushels a year to the present 2 to 3 million bushels. Yet, informed observers have consistently estimated that four to ten times the present level of harvests could be sustained with suitable management, and with development of private oyster farming as an essential element of that management.

We believe that the biological resilience of the resource and the presence of large areas of relatively unpolluted oyster ground could indeed lead to an increase in productivity and thus benefit tidewater communities that presently defend the status quo. The realization of these benefits, however, depends not on political fiat but on informed management which must in turn be based upon the best available biological information. The problems of depleted oyster harvests in Maryland are not simply biological in nature but also sociological and political.