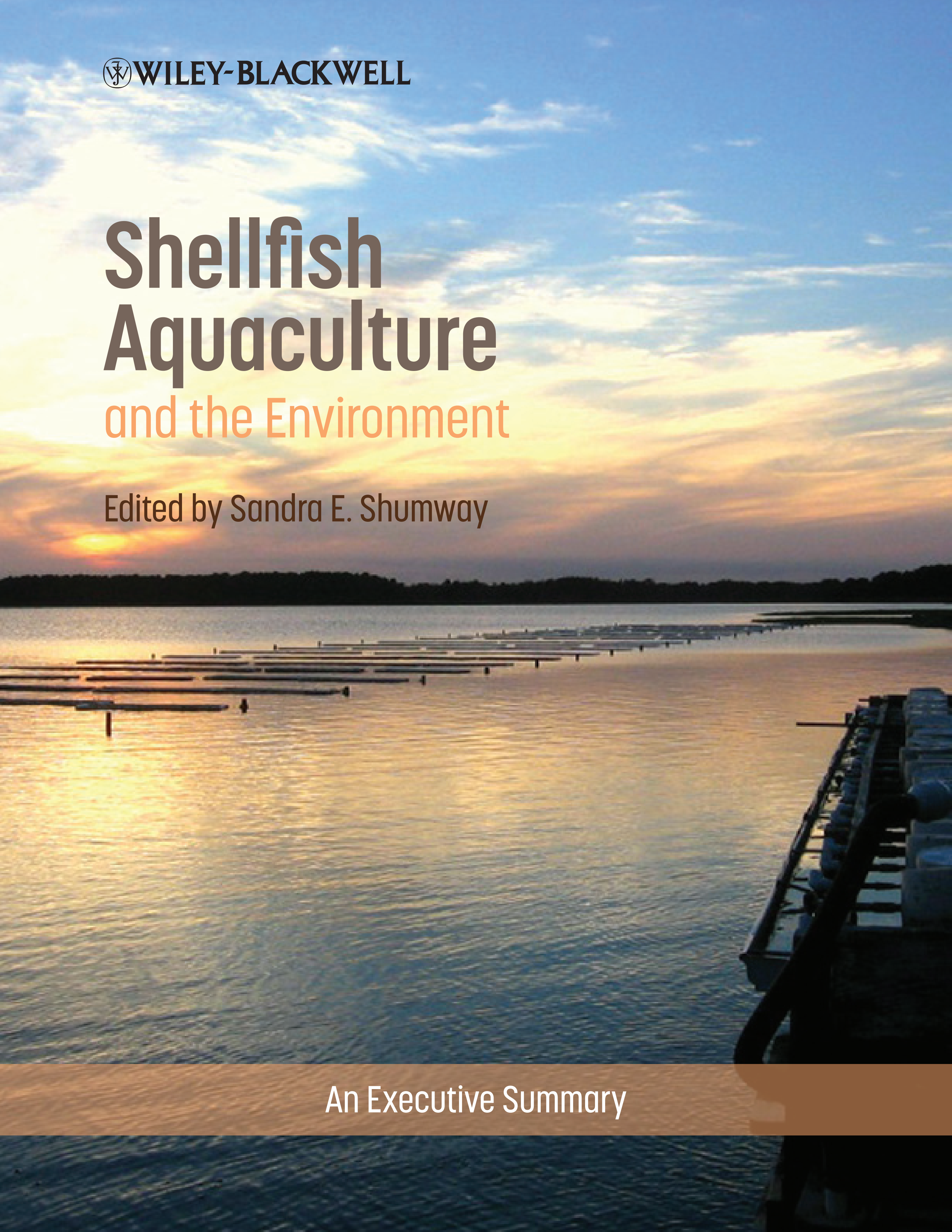

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Shellfish Aquaculture
and the Environment

Edited by Sandra E. Shumway

An Executive Summary

Background and Purpose

Production of bivalve shellfish represents a large and growing segment of the United States (U.S.) and global seafood industry with nearly 20% of domestic and 27% of worldwide aquaculture production attributed to shellfish aquaculture. The propagation of shellfish is predominantly a near-shore activity that utilizes intertidal and shallow subtidal areas held mainly in the Public Trust. As the shellfish aquaculture industry has expanded worldwide, questions have arisen about its potential impact on, and the safety of cultured product harvested from the marine environment. This uncertainty and public concern threaten to constrain further development of the industry.
A complete understanding of the effects of the marine environment on shellfish aquaculture, as well as beneficial and adverse effects that could result from the cultivated organisms and aquaculture practices is essential to those making decisions about the siting of new and existing aquaculture operations, resource enhancement and habitat restoration efforts.

The purpose of this Executive Summary is to provide a summary of the key issues and state of the science with respect to shellfish aquaculture and the environment as presented in *Shellfish Aquaculture and the Environment*. It is intended to inform the decision making processes and practices of policy makers, resource managers, shellfish biologists and industry, as well as provide science-based information to individuals who must respond to public scrutiny about shellfish aquaculture and the environment.

Credits:
This publication was prepared by Tessa L. Getchis, Sandra E. Shumway and Susan Schadt of the University of Connecticut (UConn). This project was funded in part by grant #NA08OAR4170834 from the DOC/NOAA/Oceanic and Atmospheric Research to Sandra E. Shumway, UConn Department of Marine Sciences and Tessa L. Getchis, UConn Department of Extension and Connecticut Sea Grant.

Photo Credit: Cover, Luke Breza
Inside cover, Changbo Zhu

Chapter 1

The Role of Shellfish Farms in Provision of Ecosystem Goods and Services

Authors: João G. Ferreira, Anthony J.S. Hawkins and Suzanne B. Bricker

- Shellfish and shellfish farms provide valuable ecosystem goods and services, which can be quantified using tools such as computerized farm-scale models.
- Farm-scale models are increasingly being used to assess environmental sustainability and trade-offs of traditional operations, offshore aquaculture, and Integrated Multi-Trophic Aquaculture, in the context of marine spatial planning.
- These models allow producers to calculate yield based on the size of the farm, food supply, shellfish density and environmental parameters.

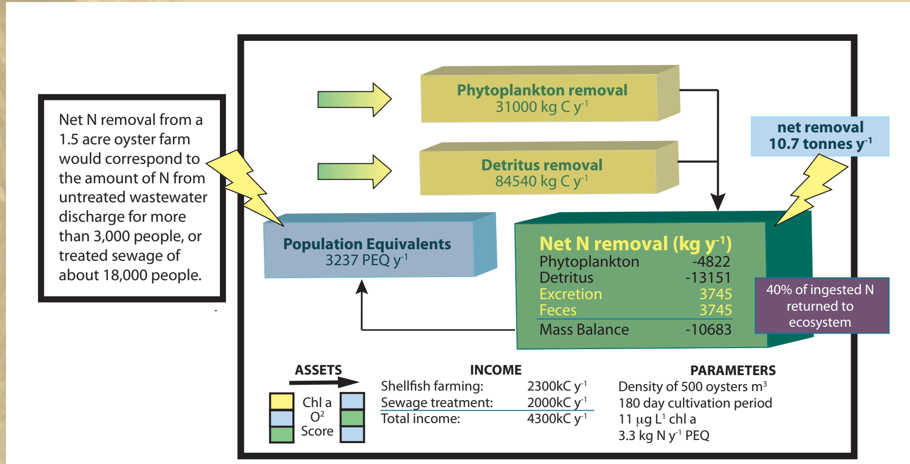


Photo Credit: João G. Ferreira

- Models are becoming increasingly more realistic as new research provides better understanding of cultivated species, interactions within the "managed" trophic web, and relevant ecosystem processes.

Chapter 2

Shellfish Aquaculture and the Environment - An Industry Perspective

Authors: William Dewey, Jonathan P. Davis and Daniel C. Cheney

Photo Credit: Tessa Getchis

- Marine aquaculture, including shellfish culture, has the potential to supply an increasingly valuable contribution of high quality protein-based foods for humans in cost-effective and community-supported sea-based systems.
- Coastal marine ecosystems that support wild shellfisheries are threatened by pollution, habitat degradation and overharvesting.
- Policy debate flourishes over the need to maintain overall ocean health while also maintaining societal dependence on the vast social and economic benefits and resources it provides. Use conflicts are common and these challenges result in significant delays and increased costs that threaten industry development in some locales.
- To prosper, the shellfish aquaculture industry is highly dependent upon: 1) the maintenance of certified growing waters located in productive, sheltered waters with access to marine shorelines; 2) a stable and predictable regulatory framework that is responsive to changes in industry practices; 3) a strong infrastructure for processing, transporting, marketing and sales of product, and for monitoring pollutants and other factors that can affect shellfish quality and safety; and 4) an educated public that embraces the quality and variety of seafood produced through marine farming.

Chapter 3 Molluscan Shellfish Aquaculture and Best Management Practices

Author: John Hargreaves

- Best Management Practices (BMP) are locally adapted, farm-scale approaches to reduce environmental impacts and increase resource use efficiency. BMP address environmental sustainability, food safety, animal health and welfare, and socio-economic considerations associated with shellfish aquaculture.
- In places with many shellfish aquaculture facilities, zoning may be more effective environmental policy tools than BMP programs to address ecological carrying capacity or local concerns.
- BMP when incorporated into industry-wide codes of conduct or environmental management systems, form the basis for ecolabeling or other product certification programs. The price premium or market access obtained through product certification can serve as an incentive to change producer practices.

Photo Credit: Sandra E. Shumway

- Small-scale producers may be unable to bear the costs associated with certification and ecolabeling programs. Larger-scale producers are often in a better position to invest in technologies and implement practices to improve environmental performance, and thus are the chief beneficiaries of certification programs based on BMP implementation.

Chapter 4 Bivalve Filter Feeding: Variability and Limits of the Aquaculture Biofilter

Authors: Peter Cranford, J. Evan Ward and Sandra E. Shumway

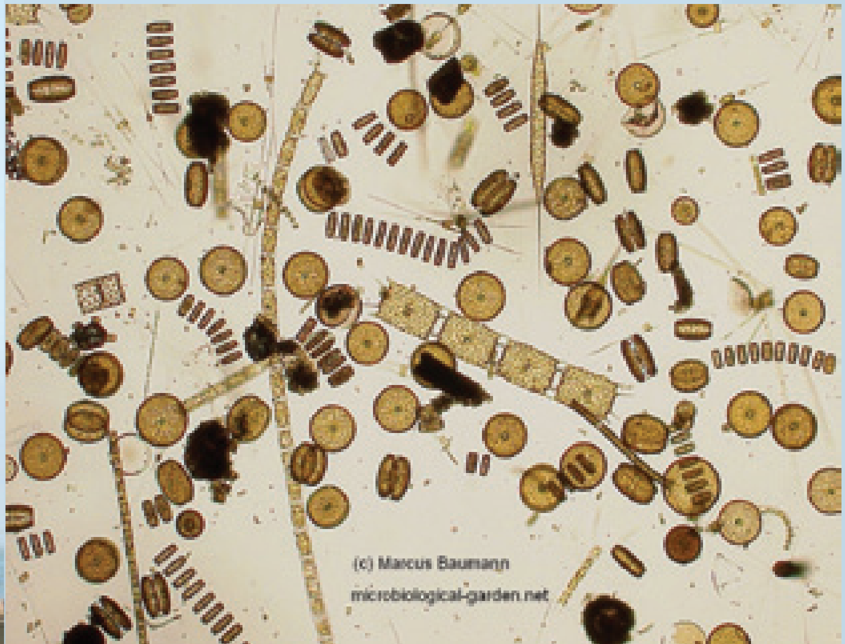
Photo Credit: Tore Strøhmeier and Øivind Strand

- Accurate knowledge of bivalve feeding ecology is needed for selection of shellfish farm locations and optimization of layout, for forecasting crop growth and site production carrying capacity, and for assessing the potential ecological services and impacts of aquaculture operations.
- Bivalves exhibit a remarkable capacity to vary feeding rates over all spatial and temporal scales relevant to aquaculture operations. Predictive relationships between feeding rate and environmental factors, such as temperature, current speed and food availability and composition, are available for the major aquaculture species.
- Review of the vast literature on bivalve clearance rates provided insights into central tendencies for different species groups, as well as the precision and accuracy of measurements obtained using available methods. Methodological pitfalls have been identified in some studies that would result in large errors if clearance rates of individual bivalves were scaled up to represent the performance of the aquaculture biofilter.
- Site- and time-specific measurements of clearance rates help improve or test model applications, and increase confidence among aquaculture stakeholders on the practical and regulatory applications of population-level particle clearance.

Chapter 5

Trophic Interactions Between Phytoplankton and Bivalve Aquaculture

Author: Gary H. Wikfors



- Microalgae, chiefly phytoplankton, constitute a large fraction of the living component of the suspended seston upon which wild and cultured molluscs feed.
- Bivalve species utilized in aquaculture tend to occur at high population densities in nature; therefore, the intensity of phytoplankton grazing by an aquaculture installation is not fundamentally different from that of a natural reef, bed, or distribution of the same species.
- Through direct excretion and remineralization of biodeposits, cultured bivalves rapidly return the nutrients nitrogen and phosphorus, but not silica, to the water, thereby sustaining primary production of non-diatom phytoplankton throughout the bivalve growing season to the benefit of all planktivores in the ecosystem.
- Bivalve aquaculture has the potential to restore pelagic-benthic coupling (the cycling of nutrients between the bottom sediments and overlying water column) and primary-producer-consumer trophic structure. In coastal waters, these functions have been irrevocably disturbed by bulkheading, channel dredging, and freshwater diversion.

Chapter 6

The Application of Dynamic Modeling to Prediction of Production Carrying Capacity in Shellfish Farming

Authors: Jon Grant and Ramón Filgueira

- Carrying capacity is defined as the stocking density at which bivalve growth is not food limited and ecosystem health is not compromised, and is a cornerstone of ecosystem-based management.
- Natural food particles can be limiting to bivalve culture yield and it is necessary to balance the biomass of farmed shellfish with respect to the amount of food available and potential production of waste.
- Bivalve growth is dependent upon food quality and quantity as well as seston flux, which is a difficult parameter to capture in the field.
- Ecological modelling provides management scenarios which preserve ecosystem services without compromising sustainability.
- Carrying capacity models are powerful operational tools.

Photo Credit: Richard Langan

Chapter 7

Bivalve Shellfish Aquaculture and Eutrophication

Authors: JoAnn M. Burkholder and Sandra E. Shumway

Photo Credit: Judy Preston

- Excessive nutrients and other pollutants from land-based human activities have degraded coastal ecosystems worldwide, destroying habitats, leaving marine life susceptible to disease and death, and promoting harmful algal blooms.
- While eutrophication has impacted shellfish and shellfish growing grounds, recent controversy has focused on aquaculture as a source of eutrophication.
- Few adverse effects of shellfish aquaculture on the environment have been documented, and evidence is limited to a few large, intensive bivalve culture operations conducted in poorly flushed areas. The vast majority (93%) of ecosystems studied have sustained either negligible or only localized eutrophication effects. These effects are site-specific and depend upon the hydrography (flushing and water exchange) and shellfish density.
- Relative to land-based pollution sources, bivalve aquaculture contributes very little to eutrophication.
- Shellfish aquaculture operations need to be protected from land-based nutrient pollution, and intensive aquaculture activity in poorly flushed areas should be avoided.

Chapter 8

Mussel Farming as a Tool for Re-eutrophication of Coastal Waters – Experiences from Sweden

Author: Odd Lindahl

Photo Credit: The Day Publishing Company

- Mussel farming is a flexible, cost-effective tool for society to recycle nutrients, mainly nitrogen and phosphorus (a limited resource on a global scale), back from sea to land.
- Cultivation of mussels and other bivalve molluscs can be regarded as "open landscape feeding" in the sea.
- Mussel farms have been compensated for the environmental service provided when improving coastal water quality.
- This type of nutrient trading has become a popular way to manage nutrient removal in coastal estuaries. Sewage treatment plants are required to assess their annual discharge of nitrogen and then pay shellfish farmers for the annual quantity removed when the shellfish are harvested.
- Mussels are not only seafood, but also a valuable resource as raw material for production of mussel meal, which can replace fish meal in feeds for poultry, pets, fish and other animals.

Chapter 9

Expanding Shellfish Aquaculture: A Review of the Ecological Services Provided by and Impacts of Native and Cultured Bivalves in Shellfish-dominated Systems

Authors: Loren D. Coen, Brett R. Dumbauld and Michael L. Judge

Photo Credit: Maryland Department of Natural Resources

Bivalve aquaculture as currently practiced can:

- provide enhanced structure and ecosystem services paralleling those generated by natural communities
- significantly reduce fishing pressure on native wild stocks (including critical shellfish-generated reef habitats)
- assist with restoration of native species

Chapter 10

Bivalves as Bioturbators and Bioirrigators

Authors: Joanna Norkko and Sandra E. Shumway

- Bioturbation (mixing) and bioirrigation (flushing) by bivalves living in or on the seabed affects the sediment stability (erosion/deposition) and nutrient dynamics of soft-sediment habitats.
- Bioturbation and irrigation increase the transport of particulates, nutrients, and oxygen across the sediment-water interface, and increase oxygen penetration into the sediment.
- Bivalves provide physical structure in the sediment and may increase habitat heterogeneity.
- Positive effects are location-specific, species-specific and dependent on the density of bivalves in the bed (cage/bag) and the extent of the bed (farm) and may switch from positive to negative at very high bivalve densities.

Photo Credit: Jessica Winder

Chapter 11

Environmental Impacts Related to Mechanical Harvest of Cultured Shellfish

Authors: Kevin D.E. Stokesbury, Edward P. Baker, Bradley P. Harris and Robert E. Rheault

- The mechanical harvest (e.g. dredging or raking) of both wild and cultured shellfish has faced scrutiny because of the potential for both short- and long-term disturbance to benthic habitats and organisms, as well as impacts on water quality and nutrient cycling.
- Shellfish farms typically operate in shallow coastal environments that are exposed to significant natural disturbance from both terrestrial and marine sources. Even so, disturbances from mechanical harvest can be substantial, but the effects are highly dependent upon the type of gear used, the frequency of the disturbance, and the resilience of the ecosystem to further change.
- The Before-After Control-Impact (BACI) experimental design provides the framework for testing harvest-impact hypotheses, and requires a data gathering and analysis program to monitor abundance of carefully selected species and/or water quality parameters.

Photo Credit: Tessa Getchis

Chapter 12

Genetics of Shellfish on a Human-dominated Planet

Author: Dennis Hedgecock

Photo Credit: Amandine Surier

- Shellfish aquaculture lacks domesticated strains and relies largely upon hatchery propagation of wild stocks. The legendary high fecundity of bivalve molluscs -- females can typically spawn tens of millions of eggs at one time -- creates a risk that hatchery-propagated shellfish stocks could dilute the genetic diversity of wild populations and possibly elevate the frequencies of harmful mutations.
- Continued farming of wild species will raise rather than lower these risks over time.
- Farming of domesticated stocks permits genetic improvement, but may elevate the risk of detrimental interactions with wild stocks.
- Farming of triploid domesticated shellfish, which are effectively sterile, permits genetic improvement while greatly reducing or eliminating negative interactions with wild stocks; in addition, containment of fertile tetraploids is an issue deserving closer attention.
- Research on developing and improving domesticated shellfish for aquaculture and on improved methods for eliminating interaction with wild populations (bio-security) would lead to sustainable management of shellfish resources.

Chapter 13

Shellfish Diseases and Health Management

Authors: Ralph A. Elston and Susan E. Ford

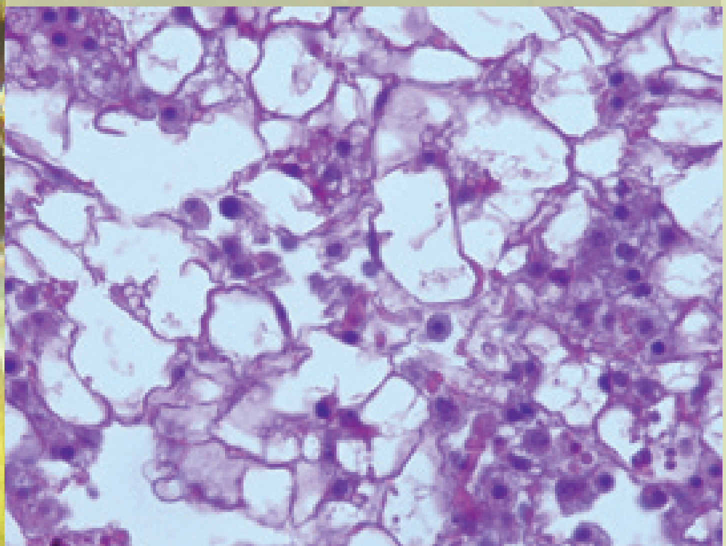


Photo Credit: Ralph Elston

- Shellfish disease outbreaks are often linked to an environmental parameter, such as salinity or temperature, but can also be directly affected by human activity.
- The transfer of diseases is a major concern as live shellfish larvae, seed, and adults are shipped domestically and internationally for commercial culture, fishery enhancement and habitat restoration efforts.
- Prevention of infectious animal disease must be managed by a system of farming protocols and management procedures (collectively "biosecurity") that maintain a healthy rearing environment, and regular testing for disease causing agents.
- Effective shellfish health management protects and preserves natural and farmed populations of shellfish.
- Shellfish health management can increase farming efficiency and eliminate wasted resources.

Chapter 14

Marine Invaders and Bivalve Aquaculture: Sources, Impacts and Consequences

Authors: Dianna K. Padilla, Michael J. McCann and Sandra E. Shumway

- Reducing the introduction and spread of nonnative species will benefit the aquaculture industry, managers, protect biodiversity and help conservation efforts.
- Historically, aquaculture of fish, shellfish, and algae, has been the second leading source of introduced marine species. Many species introduced through bivalve shellfish aquaculture have deleterious impacts on shellfish aquaculture itself. Increased awareness, changes in aquaculture practices, and strong BMP have slowed, but not stopped these introductions.
- Species with long-distance dispersal larvae can travel hundreds of kilometers and cross political boundaries. Introductions of nonnative species, even those grown in other regions of the same country or state, require special attention, and national and international efforts to develop BMPs, standards, and certification for sustainable aquaculture and to minimize the social and environmental issues associated with bivalve farming.
- Best practices to prevent accidental transfers of species, regularly included in BMP, include selecting sites for aquaculture and methods that will minimize potential fouling, cleaning or cycling of all boats, gear, and equipment that comes in contact with the water, and reporting all suspicious organisms found in an area to allow for early detection.

Photo Credit: Sandra E. Shumway

Chapter 15

Balancing Economic Development and Conservation of Living Marine Resources and Habitats: the Role of Resource Managers

Authors: Tessa L. Getchis and Cori M. Rose

- Uncertainty and public concern with respect to the ecological effects of aquaculture practices has led to changes to the manner in which shellfish aquaculture is regulated and the husbandry standards to which shellfish producers should adhere to.
- The lessons learned from the development of the marine fish farming industry have driven environmentalists, scientists, regulators and industry to investigate and document the potential for immediate and local effects resulting from shellfish farming, as well as the probability for longer-term and habitat-wide effects to occur.
- The principal concerns are generally considered to be: water quality degradation, changes in sediment chemistry and composition, habitat degradation, altered biodiversity and community structure, the introduction of non-native species including predators, pests and disease, the spread of harmful algal blooms, and the loss of genetic diversity in wild shellfish populations.
- Other major considerations in the siting of aquaculture operations include the impact to navigation and other competing uses of the coastal zone, and concern that the activity will result in undesirable aesthetic impacts, such as visual and noise pollution. These concerns have led to an increasingly complex review process.
- The regulatory community is responsible for balancing economic development, conservation of living marine resource and habitats, and other uses of the coastal zone. As such, regulators often take a conservative approach to siting aquaculture projects rather than accepting the responsibility for unforeseen risks and/or conflicts.

Photo Credit: Tessa L. Getchis

Chapter 16

Education

Author: Donald Webster

Photo Credit: Joseph Buttner

- Shellfish aquaculture education targets the hatchery, setting, nursery and growout phases of the industry.
- Many academic disciplines including biology, ecology, chemistry, physics, mathematics and engineering, among others, can be applied to shellfish aquaculture. Each has a place in educational programs designed to interest students and provide them with an appreciation of the benefits of shellfish in the environment.
- Learning skills that are useful in understanding shellfish aquaculture can be developed at many age levels of students with formal classroom activities as well as through off campus, non-credit Extension or technology transfer programs that link research with industry development.

Chapter 17

The Implications of Global Climate Change for Molluscan Aquaculture

Author: Edward Hugh Allison, Marie-Caroline Badjeck, and Kay Meinhold

Photo Credit: World Fish

- Climate change is leading to alterations in the basic biophysical processes that determine the ecological structure and function of the oceans. This will have an impact on the future of molluscan shellfish farming. The impacts may be positive or negative, depending upon location.
- The pathways through which shellfish farming may be affected by climate change are complex, but may include increased mortality and decreased growth rates from a combination of climate-change related stresses such as ocean acidification, reduced oxygenation of heated, enclosed waters, changes in primary production, changes in natural spatfall, changes in the frequency of pathogenic infections and the distribution of pests and nonnative species. Additionally, increased extreme weather events may increase losses and direct damage to aquaculture installations and coastal infrastructure.
- Molluscs are a low-carbon source of high-quality animal protein and micronutrients. Compared to meat and finfish, the 'carbon footprint' of most shellfish farming systems is low, although this will depend on energy inputs to operating the farming system, and to transporting the products to market. Life cycle analysis is needed to evaluate how to reduce further the emissions from shellfish farms. Shellfish farming does contribute to carbon sequestration.
- The hypothesized pathways of impact and evidence that change is already happening are supported by a variable quantity and quality of empirical data. The effects of acidification are potentially severe, but experimental evidence is usually based on short-term experiments and are somewhat contradictory. Tropical molluscs often live near to their temperature and hypoxia limits, and are likely to be severely affected by warming. The optimal range for temperate-zone cultured molluscs is likely to move towards the poles. Pathogenic impacts and severe weather impacts are both increasing.
- To remain viable and productive, the sector will need adaptation in its culture locations, the species grown, technology and production system management, transportation and marketing. This will likely increase the overall costs of production. Adaptation is needed both to reduce the impacts on traditional shellfish culture areas, and to seize new opportunities from improved conditions for culture in new areas.
- Molluscan shellfish farming is a small and climate-sensitive sector of the world economy, important in local economies, cultures, and as a contributor to our food. It is also a dynamic and responsive sector which already adapts to changing environments and will also adapt to climate change.

Useful Contacts

National Association of State Aquaculture Coordinators

- http://www.nasac.net/

NOAA Aquaculture Program

- http://aquaculture.noaa.gov/

USDA National Institute of Food and Agriculture Aquaculture Program

- http://www.nifa.usda.gov/aquaculture.cfm

Contact the Sea Grant or Cooperative Extension Specialist in your coastal region:

- Northeastern U.S.
  http://www.nrac.umd.edu/Contacts/index.cfm
- Southern U.S.
  http://srac.msstate.edu/aqlist.htm
- Western U.S
  http://www.fish.washington.edu/wrac/about/kec.html
- Hawaii and Pacific Islands
  http://www.ctsa.org/index.php

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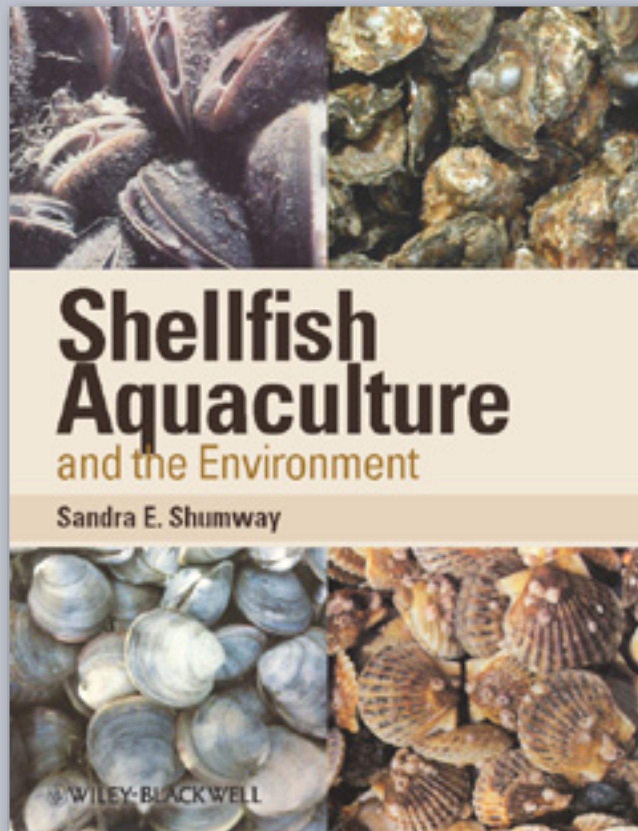

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Shellfish Aquaculture and the Environment is the first book to focus primarily on the issues surrounding environmental sustainability of shellfish aquaculture. The chapters in this book will provide readers with the most current data available on key topics, such as resource enhancement, habitat restoration, eutrophication, the impacts of farms on water quality, and harvest methods. The authors also discuss shellfish aquaculture and the environment from both industry and NGO perspectives.

Shellfish Aquaculture and the Environment will also be an invaluable resource for those looking to develop and implement environmental best management practices.

Edited by one of the world's leading shellfish researchers and with contributions from around the world, *Shellfish Aquaculture and the Environment* will be the definitive source of information for this increasingly important topic.