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Biofiltration, water quality, and sediment processes

E.T. Porter, J.C. Cornwell, L.P. Sanford, and R.I.E. Newell

Historical oyster populations in places such as Chesapeake Bay used to be able to filter algae and other particles from the water, thus regulating water quality (Fig. 220). Excess nutrient inputs and declines of oyster biofiltration have led to more turbid water, reducing the growth of benthic microalgae and affecting the exchange of nutrients between sediments and the overlying water. Oyster densities and bottom shear velocities were manipulated in mesocosm experiments to investigate their effects on benthic microalgae, nutrient regeneration from sediments, and overall water quality in the ecosystem. The mesocosm results demonstrate that biofiltration removes particles from the water column, allowing light to reach the bottom, and stimulating benthic microalgal growth, which in turn stabilizes sediments and decreases nutrient release into the water column. Realistic shear velocities have the potential to erode these benthic microalgae; however, exerting an additional physical control on benthic biogeochemical exchanges. Even considering this physical limitation, the results indicate that management efforts to increase biofiltration (e.g., oyster restoration) will have multiple, synergistic positive ecosystem outcomes.

Problem description

Over the past half-century, water quality and transparency have declined in many eutrophic

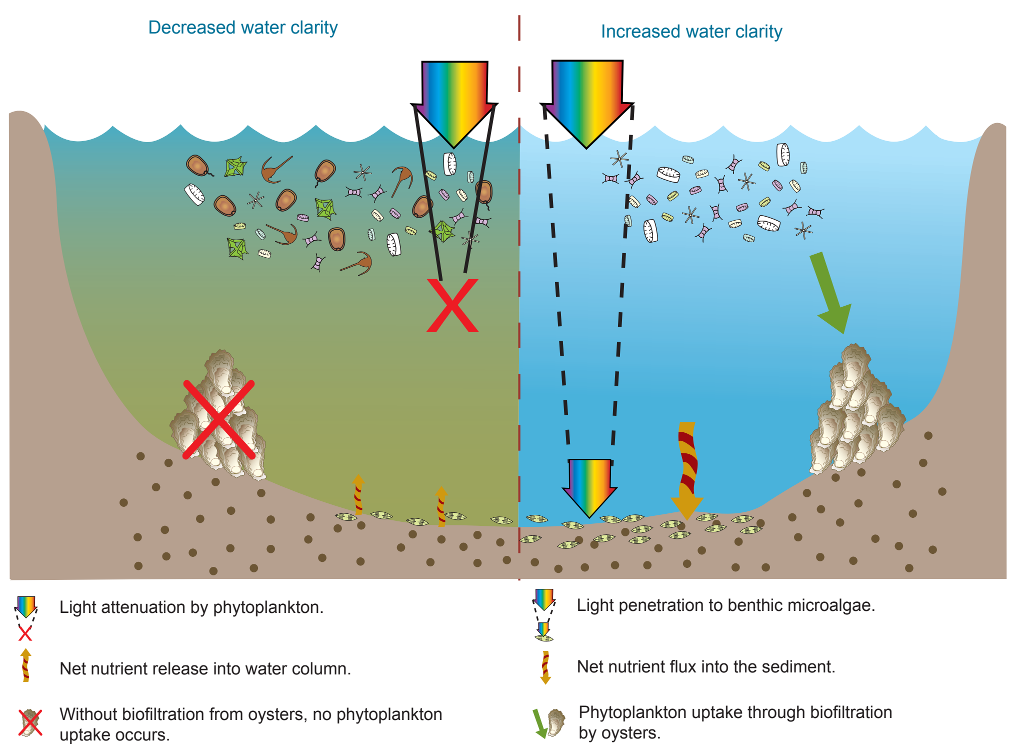

Figure 220: *Healty oyster populations can improve water quality and clarity.*

estuaries. One such estuary, Chesapeake Bay, has also experienced a concurrent decline in abundance of the eastern oyster *Crassostrea virginica* which formerly supported a productive fishery. Management authorities in Chesapeake Bay and elsewhere have recommended that water quality conditions and fishery harvest could both be improved by restoring biomass of the eastern oyster to a modest fraction of historical levels.[57] In shallow-water environments, benthic and pelagic processes are closely coupled and water flow can regulate the supply of seston to bivalves. In addition, such flow may regulate water clarity and benthic-pelagic nutrient fluxes through mixing and resuspension of bottom sediments. Until recently, the complex interactions between oysters, nutrients, water clarity, and physical circulation were poorly understood.

MEERC researchers designed a series of studies using experimental mesocosms (Fig. 221) to quantify how the combined effect of oysters and increased bottom shear velocity directly or indirectly affect ecosystem processes and shift ecosystem function between the water column and sediments.[58,59] Oysters and bottom shear velocity were used to examine effects on the following factors:

- Phytoplankton abundance in mesocosm experiments;
- Nutrient transformations and nutrient regeneration from the sediments;
- Overall water quality in whole-ecosystem experiments.

To address these questions, the interacting effects of juvenile oysters and bottom shear velocity on phytoplankton biomass and on nutrient regeneration in a series of three (spring, summer, fall) 4-week long mesocosm experiments were studied under different levels of bottom shear.[58,59] The mesocosms were 1-m deep, had a 1 m^2 sediment surface area, contained 1000 L of water, and received the same water-column mixing designed to simulate conditions in nature (turbulence intensity 1 cm s^{-1}).[58,59] A parallel set of smaller (0.1 m^3) experimental systems was used for comparative studies.[58] Experimental systems included a multi-component mesocosm with moderate bottom shear velocity (0.6 cm s^{-1}) and two standard cylindrical tanks with an unrealistically low bottom shear velocity (0.1 cm s^{-1}, Fig. 221

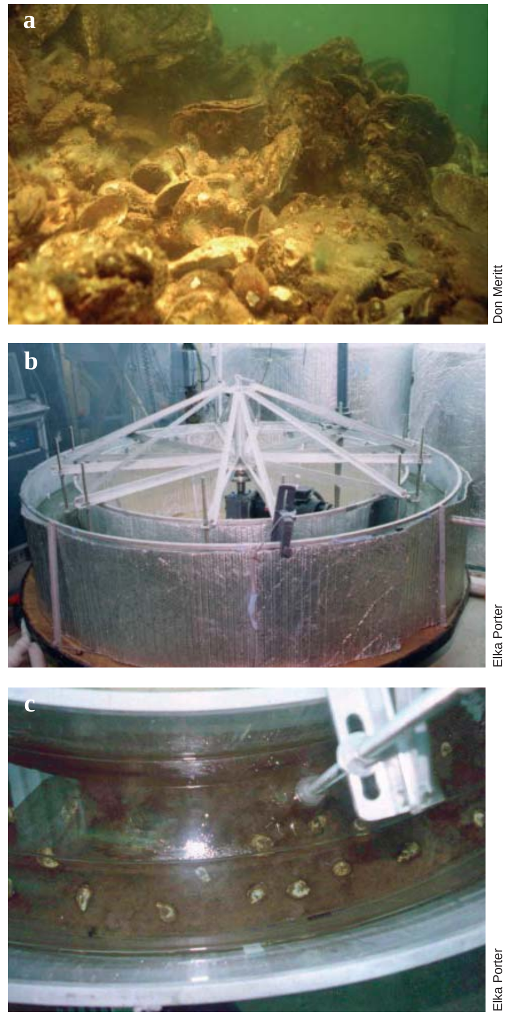

Figure 221: *Experiments were performed to investigate how oyster populations in interaction with low and moderate bottom shear affect water quality. a) Healthy oysters can improve water clarity through biofiltration. b) A large linked mesocosm with an annular flume was designed and an experiment conducted to study the interaction of water flow and oysters on water quality. c) Oysters were placed in the annular flume and water column mixing and bottom shear scaled in comparative systems.*

51. EPA 2000, 52. Porter et al. 2004a, 53. Porter et al. 2004b

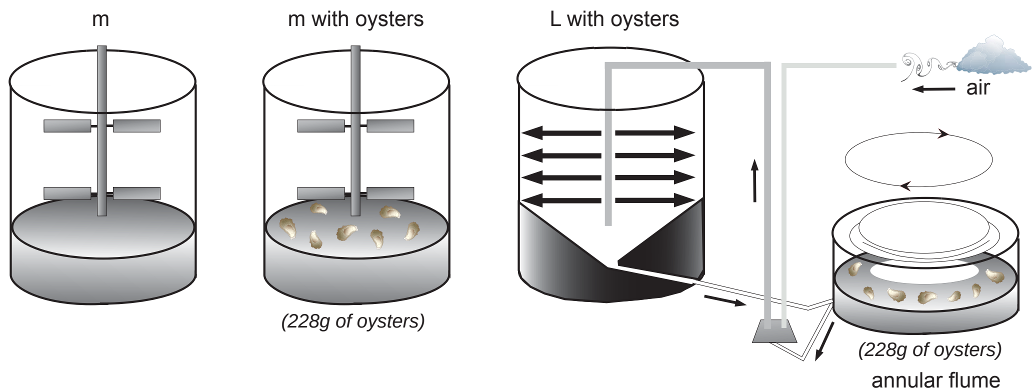

Figure 222: *Experimental ecosystems with and without oysters and low and moderate bottom shear. All mesocosms were 1 m deep and contained 1000 L of water (the linked mesocosms together contained 1000 L). Two mesocosms and the annular flume had 1 m^2 of sediment surface area. m: mesocosm with low bottom shear and without oysters; m and oysters: mesocosm with low bottom shear and with oysters; L with oysters: linked mesocosm and annular flume with moderate bottom shear and with oysters.[60] Additional experiments were conducted using a similar system of mesocosms with and without realistic benthic boundary layer shear, but with water column volumes of 100 L.[60,61]*

and Fig. 222). Experiments were run with and without juvenile oysters, using oyster densities similar to oyster abundances in historic times (19th century) in Chesapeake Bay.[60]

Research findings

It was found that direct and indirect interactions between oysters and moderate bottom shear velocity affected phytoplankton biomass, light availability in the water column and at the sediment bottom, microphytobenthos biomass, and nutrient regeneration from the sediments to the water column. Oyster feeding significantly decreased phytoplankton biomass. The isolated tank without oysters repeatedly developed a phytoplankton bloom while the mesocosms with oysters did not. The oyster-mediated decrease in phytoplankton biomass also consistently led to enhanced light penetration through the water column to the sediments.[61]


Adrian Jones

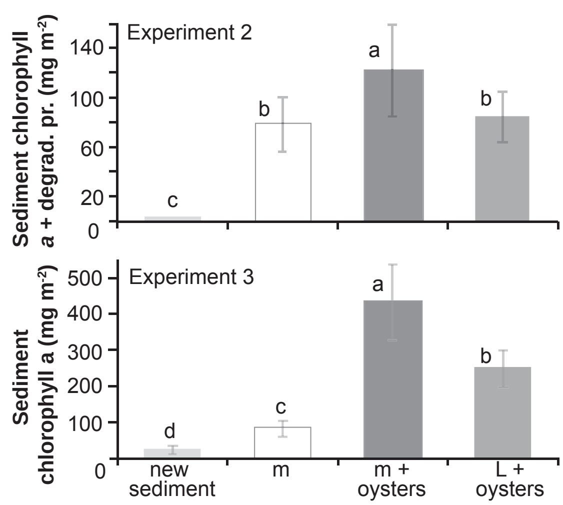

Figure 223: *Dense layers of oxygen bubbles formed from a benthic algal mat (top panel). In mesocosm experiments with moderate bottom shear these bubbles increase erosion of the microphytobenthos mat. Sediment chlorophyll* a *concentrations as indicator of microphytobenthos biomass at the end of experiments 2 and 3(right panel). Different letters indicate statistically significant differences between treatments. Treaments* m+oysters *and* L+ oysters *had the same biofiltration (i.e. increased light levels at the sediment water interface); however, a shear velocity of 0.6 cm s^{-1} eroded microphytobenthos.[61]*

60. Newell 1988, 61. Porter et al. 2004a and Porter et al. 2004b

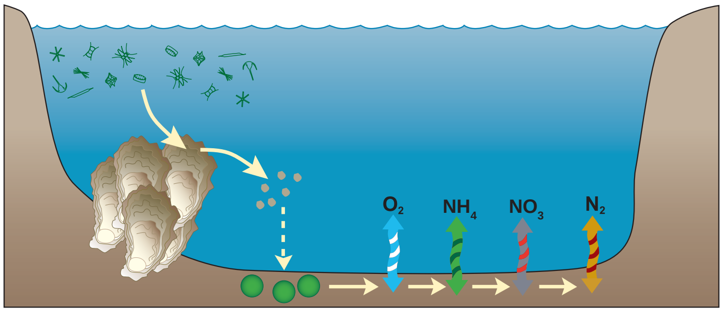

Figure 224: After consuming phytoplankton, oysters release biodeposits. These biodeposits begin the process of nutrient cycling in sediments. Benthic microalgae consume the biodeposits and coupled nitrification-denitrification takes place. This cycling was mimicked in mesocosm experiments (see Fig. 225).

Light availability at the bottom enhanced benthic microalgal biomass (Fig. 223), thereby reinforcing feedback effects to retard sediment-water fluxes of nutrients. There was a significant increase in the daily sediment uptake of dissolved inorganic nitrogen with increasing sediment chlorophyll *a* abundance. Thus benthic microalgae significantly reduced the overall amount of regenerated nitrogen that was returned to the water column. The daily nitrogen release to the water column was lowest in the system with oysters and low bottom shear (m with oysters, Fig. 222) which generated the highest microphytobenthos biomass.

In these experiments[62-64], well-developed benthic microalgal communities often formed cohesive microphytobenthos mats (Fig. 223). and microphytobenthos has been known to stabilize sediments.[64]

However, toward the end of these 4-week long experiments, bubble formation within these mature benthic algal mats tended to increase their buoyancy and benthic friction (roughness), thereby making them more susceptible to erosion by bottom shear. Consequently, experiments in systems with moderate bottom shear velocity (0.6 cm s^{-1}) exhibited substantial erosion of benthic microalgae (Fig. 223), which resulted in higher benthic nutrient recycling, despite increased light availability due to oyster feeding.[64] The sediments in the experiments described above were fine-grain (mud). These studies emphasize the importance of considering both benthic feeding and bottom shear on water quality.

Subsequent independent benthic chamber experiments demonstrated that the addition of particulate organic matter to simulate oyster biodeposits (Fig. 224) also significantly altered sediment nutrient cycling processes.[65] Experimental bio-deposition of organic matter simulating oyster processes led to small increases in ammonium recycling from sediments to overlying water (Fig. 225). However, rates of denitrification were greatly stimulated by bio-deposition, resulting in a large net removal of available nitrogen from the water column (Fig. 225). In estuaries such as Chesapeake Bay, this effect might ultimately lead to further reductions in phytoplankton biomass because of nitrogen limitation of cell growth.

Management implications

Results of these studies indicate that filter-feeding bivalves, in conjunction with water flow and bottom shear, can affect pelagic-benthic processes through a range of complex interactions. Bivalve filtration causes decreased phytoplankton biomass and increased water clarity. Clearer water promotes growth of benthic microalgae that tend to cap nutrient recycling fluxes from sediments to overlying water. Reduced benthic nutrient recycling further retards growth of phytoplankton. Bio-deposition of organic matter from oyster filtration increases nutrient delivery to the sediments but also enhances bacterial removal of fixed nitrogen through denitrification. These processes further reduce nutrient availability for sustaining phytoplankton growth. Benthic microalgal communities excrete mucus that tends to bind

62. Porter et al. 2004b, 63. Porter 1999, 64. Madsen et al. 1993, 65. Newell et al. 2002

sediment particles together, making them less susceptible to resuspension and therefore helping to maintain clearer water.

Under some conditions benthic microalgae form mats that become buoyant when bubbles of photosynthetically produced oxygen become trapped in the algal matrix. The erodablity of bottom sediments will thus depend both on bottom shear velocities and on the nature of the benthic microalgal community. Bottom shear in Chesapeake Bay is higher (1.0-1.4 m s^{-1}) than the moderate bottom shear (0.6 m s^{-1}) used in this mesocosm experiment, which likely causes additional erosion of benthic microalgae.

Experiments and models designed to aid in prediction of the effects of bivalve suspensions-feeders and water flow on ecosystems must include realistic physical conditions. Data used in models must come from experiments that consider direct and indirect effects of interactions between biological and physical components of the ecosystem. Controlled mesocosm experiments that vary physical variables like bottom shear and sediment type and biological variables like bivalve species and density are needed to further resolve the complex interactive effects of bivalves and water flow on benthic-pelagic coupling and on overall water quality. Specifically, MEERC researchers suggest the need for (1) designing a new generation of mesocosms with realistic water-column turbulence levels and high bottom shear stress, (2) conducting comparative ecosystem studies with tidal or episodic sediment resuspension and additional benthic species, and (3) considering effects of sediment type and age of benthic microalgal community on overall benthic-pelagic dynamics.

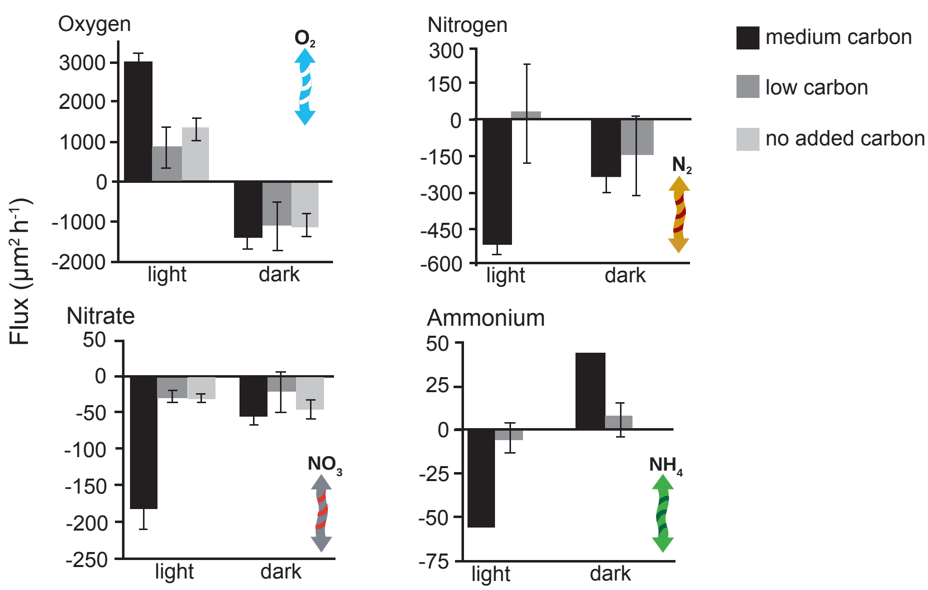

Figure 225: Light:dark experiment. Fluxes of oxygen, nitrogen gas, nitrate, and ammonium 17 days after addition of medium, low, and zero amounts of particulate organic matter. "Carbon" were added to benthic chambers. The bars indicate the means ± standard deviations). As indicated on the x-axis, sediment fluxes on the cores were determined in the light and in the dark. Positive values indicate a flux out of the sediment to the overlying water; negative values indicate flux into the sediment. Control cores only containing water to check for water column processes exhibited minor nitrogen and ammonium fluxes that do not show at the scale of these figures.

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