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Impact of high-density suspended oyster culture on benthic sediment characteristics

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ABSTRACT

Benthic impacts that may ultimately result from further intensification of suspended oyster culture in eastern Canada were proactively investigated. Eastern oysters (*Crassostrea virginica*) were placed in experimental floating rafts (12.1 m^2) designed to hold densities 2–3 times higher than those presently found in floating bag operations. Experimental rafts were moored in shallow water (1–2 m) at fixed positions where no aquaculture had been practiced. A biodeposition model predicted that the majority of feces released by suspended oysters would fall onto the seabed area directly beneath the rafts. However, field measurements over a 132 d period indicated that the fecal deposition from the highly aggregated oysters was not reflected in higher organic sedimentation rates or seabed sulfide levels. Rather, the proportion of organic matter in the top sediment layer was significantly lower in samples collected underneath rafts ($5.1 \pm 1.5\%$) than in samples taken at reference sites ($10.5 \pm 3.2\%$). This same pattern was observed for control rafts holding shells only. It is suggested that the floating raft impacted local hydrodynamic processes, forcing water to move underneath the structure, thereby amplifying turbulence and resuspending low shear strength particles such as biodeposits.

1. Introduction

In eastern Canada, the traditional approach of relaying oyster seed (*Crassostrea virginica*) to suitable bottom areas is being replaced with longline suspended culture in the subtidal zone. Novel techniques have been developed by equipping polymer mesh bags with individual floats or inserting multiple bags into a floating wire-mesh cage (Doiron, 2008). In summer, bags and cages can be flipped (180°) so as to temporarily expose fouling organisms to air desiccation (Mallet et al., 2009). Oysters grown under such conditions generally reach market-size within 4–5 years, or considerably faster than the 5–8 years normally required when grown on the bottom (Doiron, 2008). The higher cost of production of suspended culture is offset by a higher degree of consistency in product shape and meat quality which commands higher revenues.

As the industry embraces suspended culture, it also needs to address the issue of environmental impacts. Multiple floating structures distributed over large estuarine areas do appear potentially disruptive to ecological health. Presently, the literature on the benthic impacts of oyster culture deals almost exclusively with oyster tables (reviewed by Forrest et al., 2009); only a limited number of studies have focussed on suspended oyster culture. Mallet et al. (2006) found no indication of organic enrichment or benthic fauna depletion beneath floating bags. The authors concluded that their results were attributable to a combination of dynamic conditions and low stocking densities. However, Skinner et al. (2013) reported localized (<25 m) reduction in eelgrass (*Zostera marina*) biomass and productivity beneath floating bags and hypothesized this impact could be linked to light limitation.

Low stocking densities in suspended culture are attributable to longline designs that inherently require empty spaces for anchorage and navigation. In eastern Canada, floating bags and floating cages attached to commercial longlines were recently evaluated at ≤0.5 kg oysters per lease m^{-2} (Comeau, 2013). By comparison, oyster tables in France's Normandy area support 6–10 kg oysters per lease m^{-2} (Kopp et al., 2001), while oyster reef densities are roughly equivalent to 25–55 kg m^{-2} (Bastien-Daigle et al., 2007).

It is likely that suspended oyster densities in eastern Canada will increase over time. Available space for new leases has already become limiting at some sites and the testing of new rearing techniques (e.g., double bags, Dark Sea trays) is a constant reminder that the industry is still in its developmental phase. In this context, the goal of this study was to investigate near-field effects resulting from high-density suspended oyster culture. Stocking densities were experimentally amplified above current levels at a site where no aquaculture had been practiced. Sedimentation rates and

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sediment properties were monitored and compared to nearby reference sites.

2. Materials and methods

2.1. Study site properties

The experiment was performed in St-Simon Bay (47°42.36″N 64°46.12″W) inside an aquaculture lease (MS-1054) that had not yet started commercial operations (Fig. 1a).

Hydrodynamics were assessed to determine whether the site was susceptible to localized biodeposition and benthic impact. In August 2010, tidal height and current velocity were monitored over three weeks by deploying a tidal gauge (HOBO U20, Onset Computer Corporation, Bourne, MA, USA) and an acoustic Doppler current profiler (ADCP) (Workhorse Sentinel 1200 kHz ADCP, Teledyne RD Instruments, Poway, CA, USA).

A coupled hydrodynamic-biodeposition model (RMA10-RMA11; King, 1982, 2003) was set-up to provide insight into the fate of feces produced by suspended oysters, i.e., their expected spatial distribution on the neighboring seabed. The model represents a simplified case where oyster feces are produced at a constant arbitrary rate over an area mimicking a raft (5 m × 2.75 m). This suspended matter is then only subject to sinking and passive transport by the water flow. A realistic settling velocity of 0.98 cm s^{-1} was set for oyster biodeposits (Callier et al., 2006). The hydrodynamics are also simplified to a two-dimensional vertically averaged case with a uniform depth of 2 m and a uniform unidirectional flow corresponding to the observed mean current velocity. Hence, the model does not take into account any flow disturbance due to the raft. The model domain and raft position were defined in order to avoid any boundary effect in the vicinity of the raft (Fig. 2a). Model results were recorded at the end of a 24-h simulation period when the spatial pattern of biodeposition had reached an equilibrium state. The accumulated biodeposition at a given point in the domain was expressed as a percentage relative to the location with maximum accumulation.

Phytoplankton flux was assessed to gain insight on the movement of food particles. In August 2010, in situ fluorescence was monitored by deploying a Phytoflash logger (Turner Designs, Sunnyvale, CA, USA) in close proximity to the ADCP. Raw fluorescence readings were converted into chlorophyll *a* concentrations based on extracted chlorophyll measurements. Chlorophyll flux (g m^{-2} h^{-1}) was calculated as the product of chlorophyll concentration and water velocity.

2.2. Experimental stocking densities

Stocking density is function of the spatial scale under consideration. While lease scale density for the floating bag technique is estimated at 0.3 ± 0.1 kg oysters m^{-2} (Comeau, 2013), density scaled to a single longline holding mature crop is closer to 7 kg oysters m^{-2} (Comeau et al., 2006). Experimental densities in the present study were set according to the latter estimate, with the intent of amplifying culture intensity two to three fold above current practices. A raft structure (Fig. 1b) was built using individual OysterGro™ cages (147.3 cm × 91.4 cm × 15.2 cm) supplied by Bouctouche Bay Industries Ltd (Bouctouche, NB, Canada). Each raft consisted of 9 individual cages tightly attached to one another, thus creating a floating structure of 12.1 m^2 (4.42 m × 2.74 m). Each raft contained 54 bags (9 cages × 6 bags) filled with year-class 4 cultivated oysters (shell height ~62.7 mm, shell length ~44.8 mm, whole weight ~31.2 g) originating from a common lot. By varying the quantity of oysters in the bags, rafts holding the following stocking densities were created: (1) 16 kg shells m^{-2} [control], (2) 16 kg oysters m^{-2} [~446 oysters m^{-2}] and (3) 24 kg oysters m^{-2} [~668 oysters m^{-2}]. The 16 kg shells m^{-2} treatment served as a control, meant to provide information on whether the raft structure and its non-living physical content had any influence on the measured parameters. A total of nine rafts (3 treatments × 3 replicates) were deployed in a block design along predetermined transect lines in lease MS-1054 (Fig. 1c). Rafts were separated from one another by approximately 50 m. The duration of the deployment was 132 d (9 June 2011–19 October 2011).

2.3. Oyster growth

Growth was monitored to assess whether the highly stocked oysters were feeding and consequently interacting with their environment, i.e., depositing feces and pseudofeces (suspended particles rejected as unsuitable for food). Shell height, shell length, and whole weight were measured on individually labeled oysters at the start and end of the experiment. Oysters were labeled by gluing small plastic numbers onto their valves. A total of 32 oysters were followed within each raft containing live oysters. The labeled oysters were equally distributed amongst two bags (16 oysters per bag) located in the center of the rafts. The underlying rationale is that stocking density was equal in all directions radiating out from the center of the unit.

2.4. Sedimentation rates

Sedimentation rates were measured at the reference sites and directly beneath rafts by deploying sediment traps. Traps collected material for periods ranging from 6 to 15 days. Each trap consisted of two PVC cylinders (7.7 cm in diameter × 12 cm high) with a cap on the bottom and a plastic baffle fitted into the top. Each cylinder was secured with bungee cord in one corner of a plastic perforated tray weighted down with a brick. When the traps were retrieved, each replicate cylinder was swirled vigorously and the contents were transferred to an individual sampling bottle. After shaking each sampling bottle to re-suspend the sediment, two replicate subsamples of the sediment slurry were collected on pre-weighed ashed GF/C filters, rinsed with 10-ml ammonium formate, and dried for 48 h at 60 °C. After weighing to determine total sediment weight, the samples were ashed at 450 °C for 4–6 h and re-weighed to determine sediment organic content.

2.5. Sediment properties

Two 10-cc syringe core samples, each consisting of five 2-cc surface sediment sub-samples, were obtained at high tide from below each of the rafts and at each of the reference sites. Sampling was initiated on June 15, 2011, six days following the deployment of the rafts, and repeated every 1–2 weeks up until October 5, 2011. Sampling was conducted by divers who took care to minimize any sediment disturbance and avoided previously sampled areas. The cores were transferred to a 4 °C refrigerator and processed within 6 h of collection. Total free sulfide (S^{-2}) levels were assessed according to the procedures described in Hargrave et al. (1995) and Wildish et al. (1999). Measurements were carried out using an Orion (9416BN) combination silver/sulfide electrode connected to an Accumet 1003 specific ion meter. Sediment samples (5 ml) were mixed with an equal volume of freshly prepared sulfide anti-oxidant buffer (SAOB) solution. The sulfide electrode was calibrated using freshly prepared standard sodium sulfide solutions ($Na_2S{\cdot}9H_2O$—1000, 500, 100 μM). Sulfide levels were recorded when the reading stabilized (i.e. ceased increasing), or approximately 2–3 min after the sulfide anti-oxidant buffer was added. The remaining 5 ml from each sample were transferred to pre-weighed scintillation vials for the determination of water and organic content in the sediment. The samples were dried for 48 h at 60 °C and