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Feeding activity of mussels (*Mytilus edulis*) held in the field at an integrated multi-trophic aquaculture (IMTA) site (*Salmo salar*) and exposed to fish food in the laboratory

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ABSTRACT

The process of finfish aquaculture is known to release excess dissolved and particulate matter into the surrounding environment. Because of the filtration ability of the blue mussel, *Mytilus edulis*, one of the overall objectives of the integrated multi-trophic aquaculture (IMTA) approach to salmon aquaculture in the Bay of Fundy is to co-culture mussels to assess their potential to remove excess particulate matter through their feeding activities and convert this excess material into production. An objective of this study was to determine whether mussels (*M. edulis*) would ingest small particulate fish food and have the capability absorb organic material across the gut wall. A second objective was to determine if we could document the presence of excess fish food being released from the salmon farms and whether mussels would continue to feed when exposed to these excess particles. To accomplish these objectives, mussels were exposed to low concentrations of commercial fish food in flow-through seawater systems the laboratory and estimates of clearance rate (CR) and absorption efficiency (AE) obtained. There were no consistent differences in CR or AE when mussels were exposed to similar concentrations of fish food and the microalgae (*Isochrysis galbana*) in the laboratory, however these studies confirmed their capability to ingest and absorb organics from particulate fish food. In the field, mussels were exposed to the nutrient plume at three salmon farms and their feeding activity compared to mussels held at three adjacent reference locations not directly influenced by farm effluent. Feeding activity was estimated using mussel exhalent siphon area (ESA) recorded using a pair of underwater camera systems and time lapse videography. Characteristics of the suspended particles such as total particulate matter (TPM), particulate organic matter (POM), chlorophyll *a* concentration and energy content were recorded simultaneously during experiments at the three salmon farms and their reference locations. Significantly higher ESAs were recorded for mussels held at the salmon farms than their counterparts at the reference locations indicating higher feeding activity. TPM, POM and energy content of the particles were significantly elevated at the three salmon farms compared to the three reference locations, however there was no significant difference in chlorophyll a concentrations. This confirms that increases in concentrations and the energy content of suspended particles sampled at the three farms were associated with fish food effluent and not a localized increase in phytoplankton concentration. Our results show that mussels have the capability of capturing and absorbing excess particulate fish food released from the salmon farm thereby potentially reducing the nitrification process and becoming a second commercial species for export.

1. Introduction

Concerns of sustainability are associated with the rapid development of intensive fish farming in the Bay of Fundy, and throughout the world (Folke and Kautsky, 1992; Soto and Norambuena, 2004; San Diego-McGlone et al., 2008). Atlantic salmon in the Quoddy region of the Bay of Fundy are estimated to release 35 kg nitrogen (N) and 7 kg phosphorus (P) per tonne of salmon per annum, despite recent improvements in Feed Conversion Ratios (FCRs) (Chopin et al., 2001). It has also been established, in many regions worldwide, that both chlorophyll *a* and particulate organic matter (POM) levels may be enhanced by fish farming (Jones and Iwama, 1991; Lefebvre et al., 2000), but this is not always the case (Buschmann et al., 1996; Pridmore and Rutherford, 1992). These introduced excess organic and inorganic nutrients have been linked to hyper-nutrification of the surrounding environment (Ackefors and Enell, 1994; Buschmann et al., 1996).

In an effort to make fish farming more sustainable in the long term, emphasis has been placed on the practice of integrated multi-trophic

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aquaculture which is an evolved version of traditional aquatic polyculture practiced in freshwater (Ryther, 1983; Neori et al., 2007). This technique involved a fed species (such as a carnivorous fish) being simultaneously cultured with both organic extractive species (such as shellfish) and inorganic extractive species (such as seaweed). Here the nutrient losses from one species are nutritional inputs for another (Chopin et al., 2001). In theory, this practice has the potential to significantly remove excess nutrients from the system while producing potential cash crops. This practice has been utilized for centuries in Asian countries (Li, 1987; Tian et al., 1987; Liao, 1992; Edwards, 1992, 1993; Chan, 1993; Chiang, 1993; Qian et al., 1996).

Several authors have found significantly enhanced growth rates of shellfish (*e.g.* oysters and mussels) when grown with salmon (Jones and Iwama, 1991; Stirling and Okumuş, 1995; Troell and Norberg, 1998; Sara et al., 2009). However, few studies have been able to link physiological feeding responses of shellfish with salmon effluent. Lefebvre et al. (2000) reported that under laboratory conditions *Crassostrea gigas* preferentially selected and absorbed an artificial diet of *Skeletonema costatum* over faeces of sea bream. However, when not given any dietary choice, oysters did ingest (avg. clearance rate (CR) = 2.25 l h^{-1}) and absorb (avg. absorption efficiency (AE) = 56%) fish faeces. The paper by Lefebvre et al. (2000) was an important first step in understanding shellfish feeding activity when integrated with finfish aquaculture. However, there are many questions remaining with respect to the characteristics of the additional particles released from the salmon farms, rates of uptake in the farm environment, efficiency of absorption and potential impacts on shellfish growth.

The objectives of this study were: 1) to determine if blue mussels, *Mytilus edulis*, would display typical feeding behaviour or enhanced feeding rates when exposed to additional particles associated with the culture of Atlantic salmon, *Salmo salar*, and 2) to determine if *M. edulis* would ingest and absorb a diet consisting of a suspension of commercially prepared fish food. With a better understanding of mussel feeding activity at the salmon farms, scientists will be better able to estimate particle removal rates and the overall recycling efficiency of an integrated mussel–salmon culture.

2. Materials and methods

2.1. Site descriptions

Experiments were performed at three separate Atlantic salmon farms, owned and operated by Heritage Salmon, Inc., in the Bay of Fundy, New Brunswick (Fig. 1). The first site, Charlie Cove, was sampled on 22 July 2003, the second site, Frye Island, was sampled on 23 July 2003, and the third site, Fish Island, was sampled on 24 July 2003. Each site had a test location and a simultaneous corresponding reference location, 200 m away from the direct nutrient plume of the farm.

2.2. Estimating feeding response of M. edulis in the field

Seven days before the experiments, mussels 60 mm (±0.5) in shell length, had Velcro attached to their shell with cyano-acrylate glue, and were suspended in mesh socking at a depth of 2 m at the test and reference location within the fish farm sites. One hour before sampling was scheduled to begin, 8 mussels were attached to a Velcro post frame and oriented so that the exhalent siphon of each was facing the camera lens. The underwater video camera (Sony digital Handycam) was set up to record images of 2 s at intervals of 30 s (MacDonald and Nodwell, 2003). Mussel exhalent siphon area (ESA) was recorded over a 12-hour (day-length) period for mussels at both test and reference locations simultaneously using 2 camera systems.

Images of individual mussel ESAs were digitized and downloaded to the computer program Image J (2001) (NIH public domain Java image processing program-URL: http://rbs.info.nih.gov/ij), where the

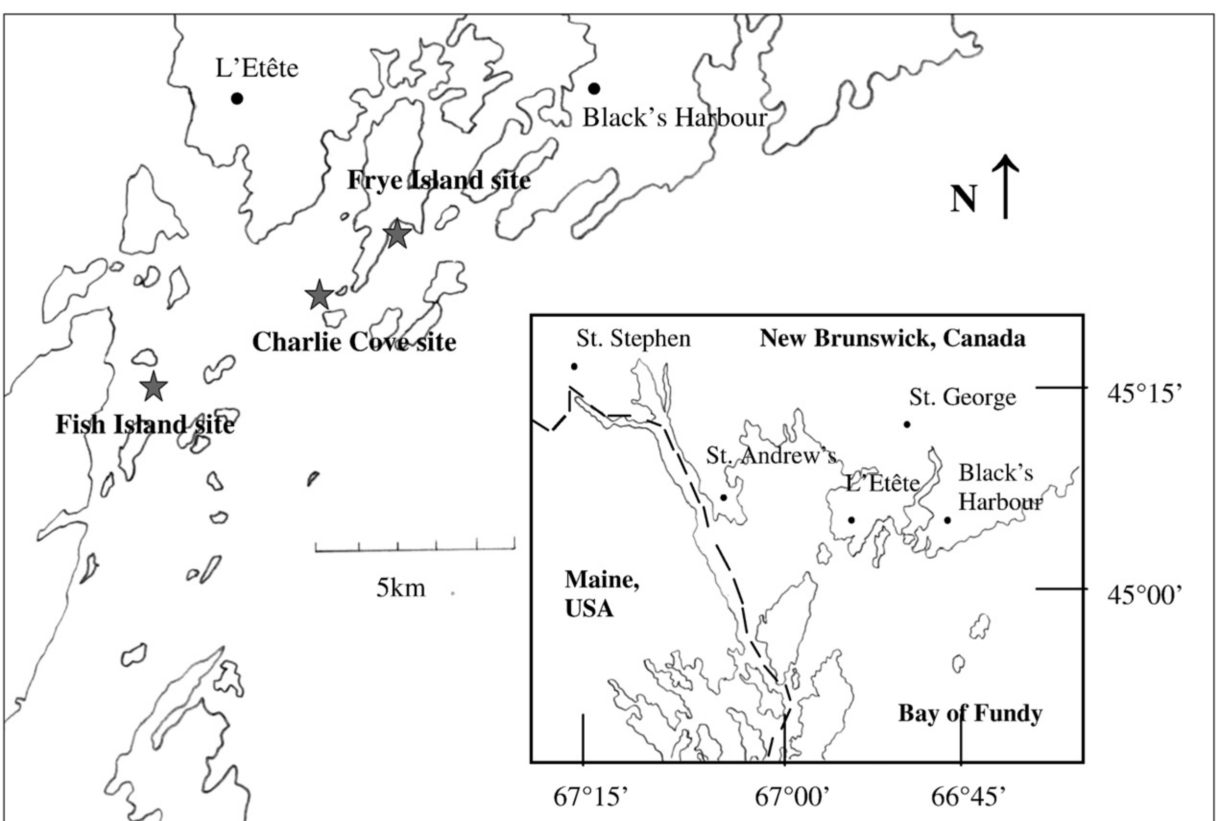

Fig. 1. Map of the three study sites in the Bay of Fundy, New Brunswick, Canada.