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Shellfish-DEPOMOD: Modelling the biodeposition from suspended shellfish aquaculture and assessing benthic effects

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A B S T R A C T

By predicting the dispersal of particulate aquaculture wastes around farm sites, numerical modelling can provide an effective tool to assess the spatial extent of environmental effects. The present paper describes how the aquaculture waste model DEPOMOD (Cromey, C.J., Nickell, T.D., Black, K.D. 2002a. DEPOMOD — modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214, 211–239.), originally developed for finfish aquaculture sites, was adapted and validated for suspended shellfish aquaculture. Field data were collected for species-specific model input parameters (mussel biodeposition rates and particle settling velocities) and several finfish model parameters (farm representation and calculation of aquaculture wastes) were adjusted for the shellfish scenario. Shellfish-DEPOMOD was tested at three coastal mussel *Mytilus edulis* farms with differing hydrodynamic regimes in Quebec, Canada. For each site, model predictions were compared to observed deposition measured *in situ* with sediment traps. Sedimentation rates under the three mussel culture sites were ca. two to five times those observed at corresponding reference sites. Mussel biodeposits were predicted to accumulate within 30 m of the farms in the shallow depositional sites while being dispersed more than 90 m in the deeper dispersive site. At the farm site in Great-Entry Lagoon, model predictions agreed well with field data for the 0+ and 1+ mussel cohorts when the maximum biodeposit production parameter was used. At the farm site in House-Harbour Lagoon, model predictions did not agree with observed sedimentation rates, due most likely to the resuspension and advection of non farm-derived material and complex hydrodynamics. The model correctly predicted the pattern of waste dispersal at the third farm site in Cascapedia Bay, although it underestimated biodeposition. Predicted fluxes may have been underestimated at this site because biodeposits from biofouling communities were not included in the calculation of aquaculture wastes. The relationship between modelled long-term biodeposition and benthic descriptors was assessed for the three farms. Alterations to the benthic community were observed at high biodeposition rates (>15 g m^{-2} d^{-1}). At the most disturbed site, predicted fluxes were best correlated with the Infaunal Trophic Index (ITI) ($R=-0.79$, $P<0.001$), followed by AZTI's marine disturbance index (AMBI) ($R=0.64$, $P<0.001$). The potential application of Shellfish-DEPOMOD in terms of the management of shellfish aquaculture sites is discussed.

1. Introduction

Suspended shellfish culture modifies pelagic-benthic energy fluxes and locally enhances the flux of organic matter to bottom sediments in coastal ecosystems via filter-feeding and subsequent biodeposition of faeces and pseudofaeces, hereafter referred to as biodeposits, by the organisms in culture. Increased sedimentation of organic matter through biodeposition may lead to changes in sediment characteristics and benthic community composition (see review by Cranford et al., 2006). Studies on the environmental impacts of shellfish aquaculture have shown that these can range from little (Crawford et al., 2003; Danovaro et al., 2004), to slight (Baudinet et al., 1990; Grant et al., 1995), to severe (Dahlbäck and Gunnarsson, 1981; Stenton-Dozey et al., 2001). The degree of environmental impact is likely related to both the site (background enrichment, sediment characteristics, and currents) and the husbandry practices (culture density and depth) (Chamberlain et al., 2001; Hartstein and Stevens, 2005; Miron et al., 2005). The culture of shellfish is generally considered to have less severe environmental effects than finfish aquaculture since

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shellfish are grown at comparatively lower biomass and no external feed is added. However, shellfish farms typically cover a much greater area than finfish farms and may thus result in very different dispersal patterns. Moreover, the size of shellfish farms is continually increasing due to improved technologies and industry consolidation. Since shellfish aquaculture is growing worldwide and farm sites are often located in shallow, low-energy coastal sites where waste material may accumulate, questions regarding the potential effect of such activities on coastal ecosystems have arisen. There is thus a need for regulators to adequately assess the potential for environmental effects.

Numerical modelling provides an effective means to evaluate the interactions between aquaculture activities and the ecosystem. To date, modelling effort with regard to shellfish cultivation has focused primarily on predicting bivalve growth and production carrying capacity rather than environmental interactions (see review by McKindsey et al., 2006). The dynamics of biodeposition, including biodeposit production rates and their potential for dispersal, are poorly understood and are not well parameterized in many models. Although biodeposits are included in a general benthic detritus compartment in some models (Bacher et al., 1995; Dowd, 2005; Grant et al., 2005), these box models are limited by their resolution and scale to accurately predict the area of benthic impact. Modelling the near-field effects of shellfish aquaculture through biodeposition has received little attention (Chamberlain et al., 2001; Hartstein and Stevens, 2005) and consequently there is a need for effective models to predict the organic flux from culture sites to the bottom (Henderson et al., 2001).

The potential "footprint" of shellfish farms, i.e. the spatial extent of the benthic impact, can be assessed with particulate waste dispersal models which may predict the dispersal of shellfish biodeposits through the water column (Hartstein and Stevens, 2005) as well as their redistribution via resuspension on the sediment surface (Cromey et al., 2002a,b; Giles 2006). The aquaculture waste model DEPOMOD

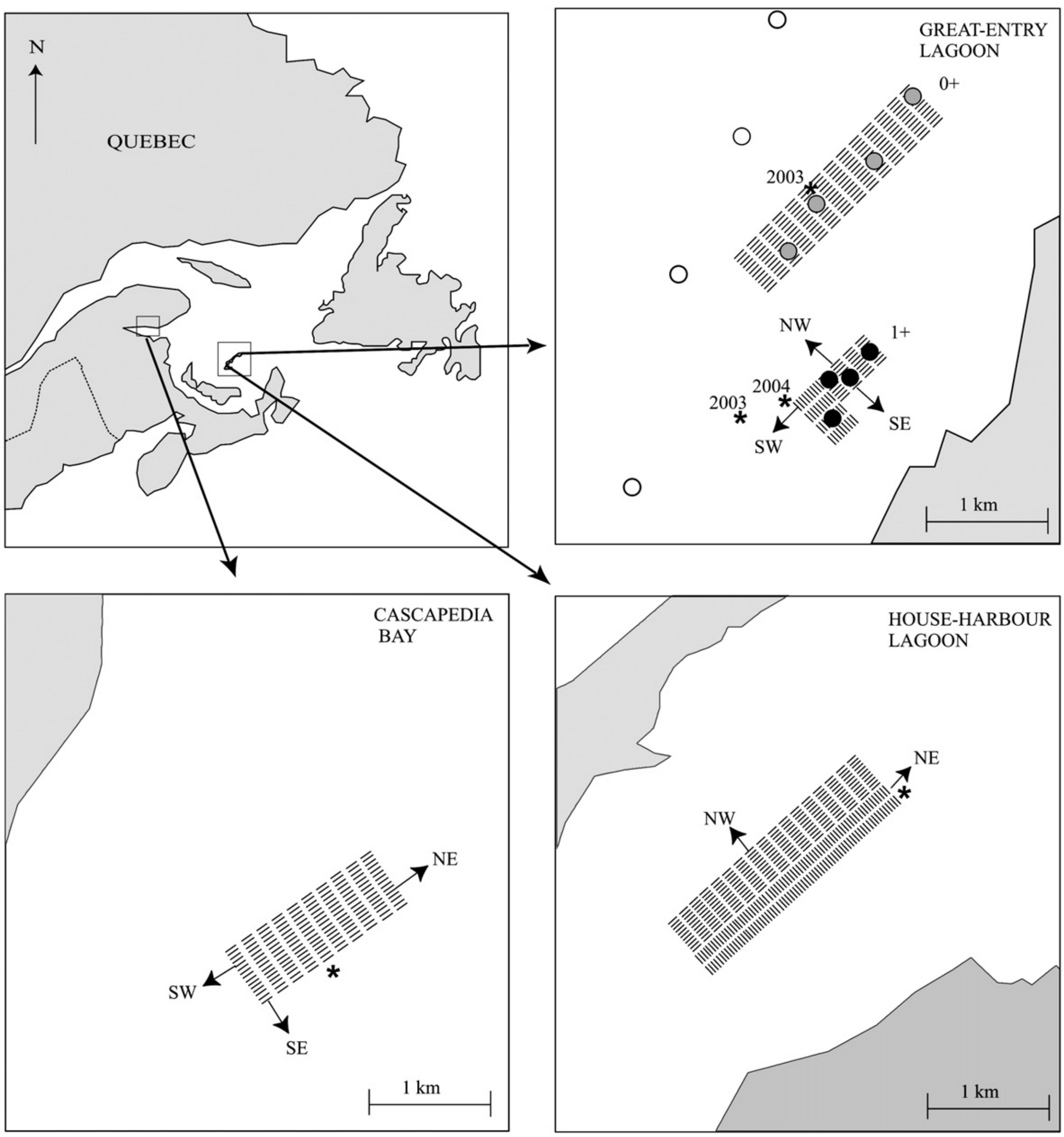

Fig. 1. Schematic diagram showing the location of the three mussel farm sites: Great-Entry Lagoon (GE) and House-Harbour Lagoon (HH) in the Magdalen Islands, and Cascapedia Bay (CAS); acoustic Doppler current profiler deployments (*); and transect directions (black arrows). In GE, the farm was divided into 2 zones based on age classes: 0+ (less than 1 year old) and 1+ (greater than 1 year old). The sampling sites for 2003 are indicated for: 0+ (◉), 1+ (●), and reference sites (○). The 1+ zone was replaced by 0+ mussels the following year. Replicate sediment traps were deployed along all transects and sediment cores were collected along the SW transect in GE, and NE transects in HH and CAS. See "Materials and methods" for details. Only sections of interest were modelled: a block of nine mussel backlines for each of the transects in GE and HH; a block of thirty mussel backlines for each of the three transects in CAS.