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A spatially resolved model of seasonal variations in phytoplankton and clam (*Tapes philippinarum*) biomass in Barbamarco Lagoon, Italy

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ABSTRACT

Barbamarco Lagoon (area = 7 km^2) is in the Po River Delta, adjoining the Northern Adriatic Sea, and supports a commercially valuable clam (*Tapes philippinarum*) fishery. This study investigated interactions of the lagoon with adjacent coastal waters and inland riverine inputs by modelling both the lagoon and the Northern Adriatic Sea, using a coupled three-dimensional (3D) hydrodynamic-ecological model (ELCOM-CAEDYM) adapted to include the clam population. The clam model accounted for carbon (C), nitrogen (N) and phosphorus (P) biomass in the benthos through parameterisations for filtration, excretion, egestion, respiration, mortality, and harvesting. Multiple clam size classes were included in a new population dynamics sub-model. Output from the coupled model was validated against hydrodynamic and water quality data from intensive field sampling and routine monitoring. Time scales of tidal flushing, primary production and clam grazing were investigated with the model to demonstrate that food supply to clam populations is dominated by phytoplankton inputs from the Northern Adriatic Sea. Effects of clam cultivation on nutrient concentrations and phytoplankton biomass in Barbamarco Lagoon were primarily localised, with strong tidal flushing minimising impacts of clam filtration on lagoon-wide nutrient concentrations at current clam stocking levels. Clam populations were found to alter the cycling of nutrients in the system, causing the lagoon to become a net sink for particulate organic matter and to export dissolved organic matter to the adjacent sea via tidal flushing. Ecosystem health and sensitivity of nutrient cycles to clam cultivation are important considerations for the long term sustainable management and potential expansion of the fishery.

1. Introduction

Bivalve cultivation sites are frequently located in shallow, well-flushed embayments or estuaries, e.g., Sanggou Bay in China (Nunes et al., 2003), Marennes-Oleron Bay in France (Bacher et al., 1998) and Venice Lagoon in Italy (Pastres et al., 2001), in order to maximise food supply to populations, whilst minimising detrimental effects of bivalve waste production. Understanding the interactions between tidal exchange, primary production, nutrient cycling and bivalve population dynamics is of critical importance in sustainably managing these fisheries.

Water temperature and food availability are the principal factors determining bivalve growth rates, both of which are strongly influenced by flow regime. Water temperature affects rates of growth through its influence on respiration, metabolism and activity in bivalves (Bayne et al., 1976; Hawkins and Bayne, 1992; Sobral and Widdows, 1997). High levels of inorganic particulates lead to reduced filtration rates, particle overload of the gills, and increase pseudofaeces production (ejection of mucus-bound, undesirable filtered particles prior to ingestion) (Goulletquer et al., 1999). Extreme ranges of salinity and low oxygen levels may also influence growth rates, causing shell closure, reduction of filtration rates and decreased food intake (Bayne et al., 1976), and may ultimately result in mortality (Uzaki et al., 2003). Grazing pressure of benthic filter feeders may significantly reduce bottom layer seston concentrations and affect dynamics of sediment deposition processes. Dense benthic bivalve communities can also contribute to oxygen depletion through respiration and mineralisation of wastes (e.g. Bartoli et al., 2001; Zaldivar et al., 2003).

Barbamarco Lagoon is a small (7 km^2), shallow (maximum depth 2 m), coastal lagoon in the Po River Delta, Italy (Fig. 1). The lagoon is the site of a commercial clam (*Tapes philippinarum*) fishery which was part of a systematic introduction to the Northern Adriatic lagoons of Italy in 1983 (Solidoro et al., 2000). *Tapes philippinarum* is a small (~50 mm length), non-selective filter-feeding bivalve that lives in sandy sediments (Nakamura, 2001) of shallow, quiescent but well-flushed areas of lagoons and estuaries (Breber,

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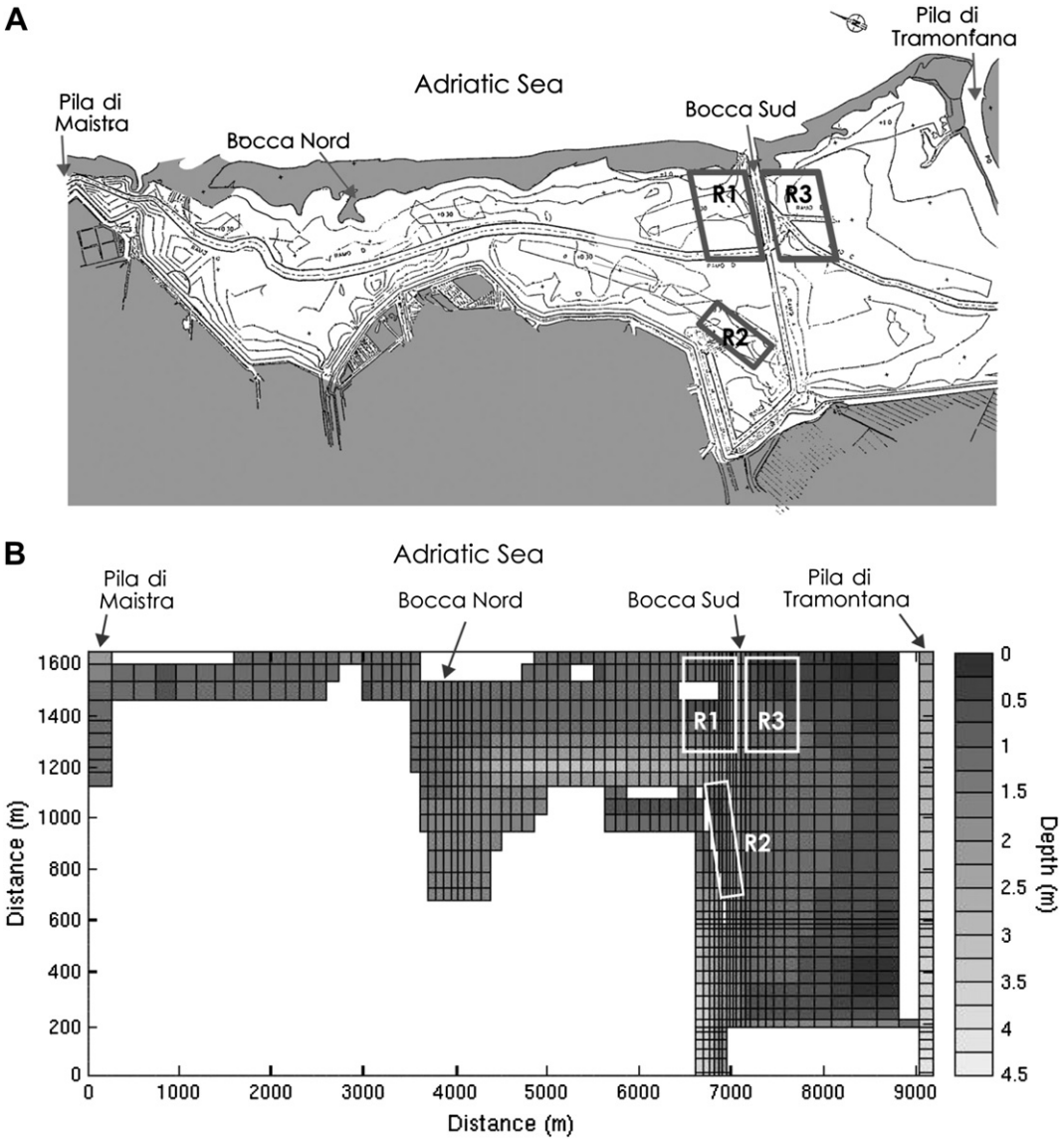

Fig. 1. Barbamarco Lagoon (A) bathymetry and (B) corresponding ELCOM bathymetry grid. R1, R2 and R3 are clam cultivation areas.

1992). In Barbamarco Lagoon the exchange of water through two main openings to the sea is the primary flushing mechanism, with conditions in the lagoon reflecting those of the adjacent coastal waters. The Po River is the primary source of land-derived nutrients to the region and its freshwater signature is evident in large parts of the Northern Adriatic Sea, depending on season and riverine discharge (Spillman et al., 2007). *Tapes philippinarum* is usually seeded in Barbamarco Lagoon during spring and summer, when water temperatures and phytoplankton concentrations are optimal for growth (Soudant et al., 2004).

Models have been applied to assess bivalve production, including bivalve growth, population dynamics, environmental responses, carrying capacity and grazing impacts. The models have generally focused on population structure, with separate age cohorts (e.g. Bacher et al., 2003; Solidoro et al., 2003; Melia and Gatto, 2005) or weight classes (Hofmann et al., 1994; Gangnery et al., 2001), or have coupled ecological models of bivalve algorithms with hydrodynamic models, to simulate food availability and thus carrying capacities for bivalve populations (Ferreira et al., 1997; Bacher et al., 2003; Duarte et al., 2003). Capacity to adequately resolve the hydrodynamics is essential for predictions of food availability and hence, bivalve growth rates. The absence of a physiological food threshold in models can also lead to overestimations of clam growth at phytoplankton densities as high as those in Northern Adriatic lagoons (Solidoro et al., 2000). Pastres et al. (2001) used a coupled three-dimensional (3D) ecological and hydrodynamic model to investigate clam growth, but did not include nutrient feedbacks or population dynamics, in common with most other bivalve models.

In this study we use a combined hydrodynamic-ecological model of bivalve biomass and cohort structure with water circulation, with the primary objective to elucidate the temporal and spatial variability of food supply to commercially valuable clam populations of Barbamarco Lagoon. We hypothesised that the Northern Adriatic Sea supplies the bulk of phytoplankton biomass required to support clam populations in the lagoon, as strong tidal flushing (Rameriz, 1999) coupled with nutrient-rich but phytoplankton-poor riverine inputs via inflow channels, result in limited in situ contributions to the clam food supply in the lagoon. To test this hypothesis a coupled 3D hydrodynamic-ecological model was adapted to include a comprehensive sub-model of clam dynamics. The model incorporates many interacting physical (tidal flushing, stratification) and ecological (clam cultivation, primary production) factors in order to assess