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Natural resources and climate change: A study of the potential impact on Manila clam in the Venice lagoon

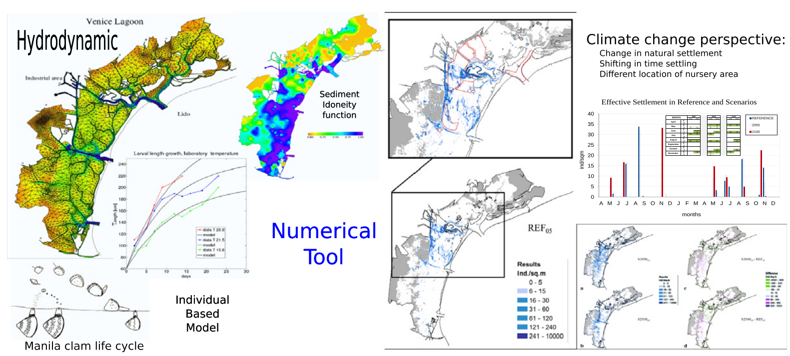
Michol Ghezzo[a,*], Michele Pellizzato[a,1], Francesca De Pascalis[a], Silvia Silvestri[c], Georg Umgiesser[a,b]

[a] Institute of Marine Science - National Research Council (ISMAR-CNR), Arsenale Castello 2737/f, 30122 Venice, Italy
[b] Marine Research Institute, University of Klaipeda, Herkaus Manto str. 84, 92294 Klaipeda, Lithuania
[c] CAB International, 9, Muthaiga - Limuru Road, PO Box 633-00621, Nairobi, Kenya

HIGHLIGHTS

- Knowledge of nursery and natural settlement is crucial for shellfish farm management.
- Combining hydro-bio-lithosphere for predicting Manila clams response to climate change.
- Numerical modeling can reproduce larvae settlement dynamics and nursery vulnerability.
- The model shows crucial features influencing larval settlings due to climate change.
- Presented tool can be used to develop a clever sustainable adaptive management.

GRAPHICAL ABSTRACT



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ABSTRACT

A crucial aspect in climate change is to understand how an ecosystem will adapt under different environmental conditions and how it will influence the ecological resources and the connected human activities. In this study, a numerical model reproduces the growth dynamics, dispersion and settlement of clam's larvae in the Venice lagoon. On the basis of the last IPCC scenarios for the years 2050 and 2100, the model simulates the changes in larval settlement, showing how the geographical distribution and, consequently, the nursery area changes over time.

Our results indicate that climate change will modify, not only the timing of the settlements (from spring–summer to winter autumn) and the spatial distribution of nursery areas (from central to southern lagoon), but also the absolute quantity of settled larvae in the lagoon. This can strongly affect aquaculture in terms of availability of seed and farming practice. Given that these changes are due to the variations in temperature and circulation, similar processes are likely to happen in other transitional environments all over the world affecting the global aquaculture resources. In this regard, the tool we developed could support local policy-makers in the knowledge-based planning and sustainable management of clam aquaculture in vulnerable environments.

1. Introduction

Aquaculture is one of the fastest growing producing sectors in the world and experts have estimated it will supply 65% of all human seafood consumption in 2030 (Word Bank, 2013). Molluscan shellfish

* Corresponding author.
E-mail addresses: michol.ghezzo@ve.ismar.cnr.it (M. Ghezzo), michele.pellizzato@libero.it (M. Pellizzato), francesca.depascalis@ve.ismar.cnr.it (F. De Pascalis), s.silvestri@cgiar.org (S. Silvestri), georg.umgiesser@ismar.cnr.it (G. Umgiesser).

[1] Michele Pellizzato is a Freelance Biologist Consultant.

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in 2012 accounted for 23% of total (inland and marine) aquaculture production and 60% of the world marine aquaculture production. The market is composed of 4 main groups of bivalva: clams, oysters, mussels and scallops represent the 80.7% of the total production. Italy is in the top 10 countries for mollusc aquaculture, representing the 0.7% of the world production (FAO, 2014). Italy is also the leader in Europe for this activity with the north-east Adriatic sea as the most productive area (Scientific, Technical and Economic Committee for Fisheries, 2014; Scarcella and Cabanelas, 2016), due to the presence of several shallow coastal lagoons.

Several authors (Boscolo Brusá et al., 2013; Gaspar et al., 2012) underline that some challenges to the full development of clam aquaculture still remain: 1) the availability of spat and 2) the management of nursery areas. The clam aquaculture is based on the seeding of spat and juveniles in the farm area. The production of seed is done artificially in specific plants, but they can offer only a limited number of seeds. Another way is to collect spat and juveniles from nursery areas, where they naturally are settled with high density. This "wild" seed is abundant, more economic and more resistant in the environment. Consequently it is very important to locate nursery areas and understand which factors contribute to create these natural settlement areas. The mixing practice of wild and laboratory seed is common in bivalve aquaculture (FAO, 2004), therefore, the sector relies also on natural settlements at the early life stage and recruitment. Thinking from a resource management and climate change perspective, a number of questions arise about how the clam culture will change and which effective management tools can help us to mitigate the impacts.

The Venice lagoon is a relevant example of the "wild-natural" seed mixing practices. The lagoon is one of the largest transitional systems of the Mediterranean where, for centuries human intervention has shaped the environment, exploiting its resources and where the management issue is a daily challenge. We developed a numerical tool to study how the clam culture will change in the future in the lagoon, as a relevant case study in terms of clam production value, data availability and need of integrated management.

Manila clam has a juvenile plankton spat stage and a benthic adult stage, with a time elapse between the two different life stages of about 20–30 days (Helm and Pellizzato, 1990; Paesanti and Pellizzato, 2000). During the planktonic stage the larvae are passively transported by the currents, therefore the adult organisms may grow in an area far from where they have been generated. The transition of the larvae from planktonic to benthic habitats exposes them to different environmental conditions and the early settled post-larvae presents a high level of mortality (Helm et al., 2004). The benthic stage, which includes settlement and post-settlement, plays a key role for the success of the overall recruitment process (Roegner and Mann, 1995).

An increasing number of biophysical models to predict the larval dispersal and settlement of marine benthic species is going to be applied in lagoons and estuaries because they provide important nursery grounds and adult habitat for exploited benthic commercial invertebrate. Starting from (Chícharo and Chícharo, 2001; Chićharo et al., 2001) modeling the growth of *Ruditapes decussatus* on the basis of temperature and water advection, other studies are moving toward high resolution hydrodynamic models coupled with complex larval dispersal models to predict the movement of particles taking into account the physical transport and larval behavior (Herbert et al., 2012). Settlement modules including also habitat suitability approaches are going to be applied to better understand recruitment success and post-settlement mortality (Hinrichsen et al., 2009; Bidegain et al., 2013).

In this study we developed an individual-based model of the *Ruditapes philippinarum* larval phase, adopting the lagrangian ensemble methods coupled with a spatially explicit hydrodynamic model. The larval development and settlement processes under different environmental conditions are represented by a metabolic module. The larval dispersion is simulated associating the metabolic module to a particle tracking module coupled to a finite element hydrodynamic model. The obtained tools simulate the population history representing the development of individuals, allowing us to assess the evolution and availability of the natural settled clam spat resource. We calibrated the tool in the lagoon of Venice simulating the settlement of early stages under realistic reference condition. Successively, we modified the environmental variables according to the climate change projection proposed by Ferrarin et al. (2014) to study how climate changes will influence reproduction, growth, dispersion and settlement, and how it will affect the suitability of different lagoon areas.

2. Study site

The Venice lagoon is the most extended lagoon of the Mediterranean Sea, connected to the Adriatic Sea through three inlets which guarantee the water exchange: Chioggia (500 m wide, 8 m depth) and Malamocco (500 m wide, 14 m depth) and Lido (1000 m wide, 14 m depth) from South to North. The lagoon average depth has been estimated around 1.2 m and 75% of the total surface area has a depth of less than 2 m (Molinaroli et al., 2007). The sediment is mainly composed by clayey silt with a mud fraction around 80% of dry weight, with the proportion of mud fraction decreasing from the North to the South (Molinaroli et al., 2009).

Tide and wind are the main factors regulating water level, circulation and sea exchange (Umgiesser et al., 2004; Pirazzoli, 1991). The discharge of several rivers contributes freshwater giving rise to the brackish profile of the lagoon salinity (Ghezzo et al., 2011). The water temperature has a clear seasonal cycle varying between 3 °C to 24 °C, with maximum values greater than 35 °C and local minimum values less than 0 °C (Tagliapietra et al., 2011).

The Venice lagoon was characterized by an abundant and diversified phytoplankton community (Bernardi Aubry et al., 2004). The algal blooms generally start from the inner part of the lagoon and are fast extended to the whole lagoon. The trophic characteristic of the lagoon has changed reducing in time (Facca et al., 2014) and also the phytoplankton community followed this trend. Breber (2002) observed that larval stages take their diatom diet from the plankton, so checking the phytoplankton availability we see that it has been estimated to never be lower than 2 μg/l, meaning that, at least in the studied years, no limitation for the larval growth (Bernardi Aubry et al., 2013; Paesanti and Pellizzato, 2000) can be assumed.

The Manila clam (*Venerupis (Ruditapes) philippinarum*) was introduced in the Venice lagoon in 1983 by a regional governmental agency for experimental purposes (Pellizzato, 1990a), and subsequently it spread in the other coastal lagoons of the northern-east Adriatic Sea (Goro, Scardovari, Marano-Grado) demonstrating a great capability to colonize temperate shallow lagoons (Pellizzato, 1990b). Within a few years *V. philippinarum* it became the most important commercialized species in Italy, with 95% of the overall production coming from the Northern Adriatic area. In particular, the Venice lagoon production reached a peak of over 64,000 t y^{-1} equivalent to the 60% of the total Italian yearly production at the end of 90s (Pellizzato and Da Ros, 2005; Zentilin et al., 2008). The production has since followed an irregular trend, showing a drastic decline in the year 2000 and again an increase in the following years (Pellizzato et al., 2011; Ponti et al., 2017). Actually the trend of production is variable year-by-year.

The aquaculture activity from 1999 was limited because of its the pressure on the environment. The local authorities assigned to the fishermen specific parts of the lagoon, called *"concessioni"*, to use as farming areas (G.R.A.L, 2006, 2009, 2011).