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Editorial

Will Climate Change Endangers the Current Mussel Production in the Rias Baixas (Galicia, Spain)?

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Abstract

All coastal systems present a unique hydrodynamic configuration that results in the development of numerous site specific fish and shellfish species. Nowadays, main topics of research include the climate change impacts on these coastal systems and the identification of critical conditions for resident species development considering their effect on local economy. The present study aims to investigate the climate change impact on the aquaculture sector in the Rias Baixas (Spain), where mussels are the specie with higher economic value. Local hydrodynamic changes were assessed through implementation and exploitation of a hydrodynamic model (Delft3D), in order to identify changes on salinity and water temperature patterns and their possible impact on mussel's production. The first step on model implementation comprised the assessment of its accuracy performed through the calibration procedure, which included the comparison between observed and predicted sea surface elevation, salinity and water temperature for different monitoring stations. After, Rias Baixas salinity and water temperature were predicted for past and future scenarios (1995-2005 and 2090-2100, respectively), and changes assessed considering the range ideal for mussels production. It was concluded that Ria de Arousa and Ria de Vigo will be the most affected by climate change, since salinity and water temperature will surpass the critical values where aquaculture is profitable. The least affected by climate change is the Ria de Pontevedra as only salinity surpasses the critical values.

Keywords: Aquaculture; Coastal warming; Rias Baixas; Salinity; Water temperature

Introduction

The dynamics and patterns of coastal systems physical properties are strongly influenced by atmospheric conditions, wind stress, rivers discharges and tide propagation. The existence of a ria, described as a recess in the coastal zone resulting from the submersion by the sea of the terminal zone of a fluvial network, induces the interaction between freshwater of fluvial origin and salt water of marine origin, affecting coastal currents as well as the local thermohaline patterns. These dynamics turn this kind of systems more biological productive than rivers and oceans, since they are richer in nutrients, which stimulate the growth and development of local organisms living there [1]. Therefore, to understand and predict the dynamics of these systems is an important challenge, mainly due to their economic and ecological potential. Following this concept, the idea of cultivating various species of fish and shellfish with commercial value in these systems arises and consequently the aquaculture activity is developed within estuaries, lagoons or Rias.

Galicia, located in the northwest of Spain, is by far the largest production area in the country, with more than 90% of all mussel production. According to different estimates, between 150000 and 200000 tons are produced annually from aquaculture in Spain, of which the mussel *Mytilu sgalloprovincialis* comprises 97%. The remaining percentage is distributed among the oyster (*Ostreaedulis L.*) and other species [2,3]. The Galician mussel production is considered the largest in the world, and the sector directly generates more than 8000 jobs and incorporates 1000 aquaculture support vessels. The annual production accounts for approximately half of the world production of this mollusk, placing Spain foremost among world leaders in aquaculture. Approximately 70% of the Spanish mussel production is destined for internal consumption, and the resulting 30% is exported, mainly to Italy and France.

The Galicia coast is characterized by four estuaries located south of Cape Finisterre, locally named as Rias Baixas (Figure 1). These ecosystems have enormous potential, being characterized by a high primary production, which is largely responsible for the high fisheries and aquaculture productivity of the region [4]. By these reasons the Rias Baixas were subjected to continuous monitoring of the most important areas of aquaculture during the last decades. Aquaculture activity was first implemented in the Rias Baixas around 1946, beginning in the Riade Arousa with the introduction of mussel production [5]. Currently, this production is carried out on floating platforms named by rafts, which occupy an area of 500 m² having up to 500 strings associated (12 m in length). It is in these strings that the mussels are cultivated [6]. Due to the high economic success of the local aquaculture activity, the density of these floating platforms has been increasing over time. Recently, Duarte et al., [7] carried out a study that revealed that the total number of platforms in the three rias under study is 3116, and the ria with the highest density is the Ria de Arousa with 2292 platforms, followed by the Ria de Vigo with 478 platforms and finally the Ria de Pontevedra with 346 platforms. As previously mentioned, the main mussel species produced on these platforms is the *Mytilus galloprovincialis*, better known as the Mediterranean Mussel. This species has a high tolerance to changes in water temperature and salinity, and a high resistance. About the water temperature, Anestis et al., [8] demonstrated that this species presents high levels of mortality at temperatures above 24ºC, while the highest growth rates are reached at temperatures ranging between 10ºC and 20ºC [9]. Concerning salinity, this species is very sensitive to low values, since

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they affect its shell structure and composition [10]. This species can, however, survive under a relatively broad range of salinity, from 20 to 36, although its highest growth rates are found for salinities above 34 [11].

Considering this, there is a special concern about the impact that climate change can have on the dynamics of these systems, specifically water temperature and salinity resulting patterns. In general, these changes may manifest in many ways, but some of their most devastating consequences consist on the increasing of ocean water temperature, decreasing of river flows and rising sea level, affecting the local hydrodynamic as well as the water column biological activity [12].

This study aims to perform a preliminary research to predict the impact that climate change may have on mussels' production in the Rias Baixas. A two-dimensional model forced by atmospheric and oceanic variables derived from local scenarios of the 5th IPCC report was implemented and the results explored. Numerical results were analyzed to assess changes of salinity and water temperature patterns caused by climate changes, identifying critical areas for mussels' production.

Study Area

The Rias Baixas are located in the northwest of the Iberian Peninsula, more concretely south of Cape Finisterra, forming a set of four rias. For the present study, only the three most important, the Ria de Vigo, the Ria de Pontevedra and the Ria de Arousa (Figure 1) were considered. The three Ria have a V-shaped configuration, progressively widening their width from the innermost part to the mouth of the ria, and are connected to the open sea by two entrances, defined by islands in their outermost part. The three rias are fed by freshwater discharge from the rivers Oitavén - Verdugo that flows into the headwaters of the Ria de Vigo, the river Lérez that flows into the Ria de Pontevedra and the rivers Umia and Ulla that flow into the Ria de Arousa.

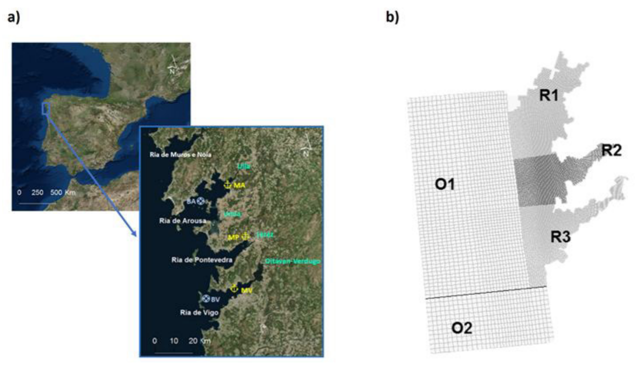

Figure 1: (a) Map of Rias Baixas, indicating tide gauges (yellow anchor) and buoys (blue buoy). (b) Multi-domain horizontal grids (Ria de Arousa (r1), Ria de Pontevedra (r2) and Ria de Vigo (r3), Ocean Boundary (o1 e o2).

All the dynamics and circulation in the rias are forced especially by the tidal currents, the wave regime adjacent to the rias, the wind stress, the interaction with the atmospheric processes and the river discharges. These influence the distribution of salinity and water temperature in the rias, both horizontally and vertically. It should be noted that tidal currents constitute the main forcing of the dynamics of the three rias. The tides on the west coast of Galicia are mesotidal, varying its amplitude between 1.1 m and 3.5 m during neap and spring tides, respectively [13].

Methodology

Numerical model implementation

In order to fulfill the main objective of this work, the DELFT3D model was used and the 2D application of the FLOW module was chosen, since three dimensionality was not required as the upper layers of the water column are the most important to the present study. DELFT3D is a software for computations of coastal, estuarine and river areas developed by Deltares in the Netherlands.

The first step of the methodology consisted in the implementation of the numerical model most indicated for the Rias Baixas, through the development of five irregular numerical grids (Figure 1b), based on bathymetric data obtained from General Bathymetric Chart of the Oceans. The grids for the three rias (R1, R2 and R3, Figure 1b) have a resolution varying from 300 m × 300 m to 550 m × 300 m, while the two grids representative of the continental shelf (O1 and O2) have a lower resolution (with a ratio of 1:3 comparing to the grids developed for the three Rias) (Figure 1b).

The model uses tidal data from TOPEX / Poseidon, salinity and water temperature from two buoys present in the Ria de Arousa and Ria de Vigo, available by MeteoGalicia (http://www.meteogalicia.gal/) as oceanic open boundary conditions. The river discharges for the rivers flowing in the Rias Baixas were imposed at fluvial open boundary conditions, and were obtained by accessing the Hype Web portal (http://hypeweb.smhi.se/). Atmospheric data from the ERA Interim daily (http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/) was used as surface boundary conditions.

In order to evaluate the impact of climate change on the aquaculture sector of the Rias Baixas it was necessary to define adequate scenarios, with proper boundary conditions, different from those mentioned above. Thus, two simulations were carried out, each with a period of 10 years: a simulation referring to the past (1995-2005) and a simulation concerning the future (2090-2100). Atmospheric values were obtained from Regional Circulation Models (RCMs) from the CORDEX project (http://www.euro-cordex.net/) with a horizontal resolution of 12.5 km. The salinity and water temperature were obtained from Global Circulation Models (GCMs) from CMIP5. The RCM RCA4 was used, being forced by four global GCMs, CNRM-CM5, HadGEM2-ES, IPSL-CM5A-MR and MPI-ESM-LR. A single scenario for the future, RCP 8.5, was considered, representing a radioactive forcing of 8.5 W m^{-2}. The mean sea level was obtained from the TOPEX solution, using the same level for the two simulations. The river discharge values required to perform the past simulation were obtained by accessing the Hype Web portal. For the future simulation, it was found that the most pessimistic prediction anticipated a reduction of 25% in the river discharges to the region of the Rias Baixas. Thus, this reduction was considered for the climatological values previously obtained (1981-2010).

Numerical model assessment

The accuracy of the model predictions for the Rias Baixas was evaluated through a qualitative and quantitative comparison between Sea Surface Elevation (SSE), salinity and water temperature predictions and concurrent *in situ* data available from Puertos del Estado (http://www.puertos.es/en-us/oceanografia/Pages/portus.aspx) and Meteogalicia.

Firstly, a visual comparison between observed and predicted time series of SSE at Ria de Vigo and Ria de Arousa (Figure 1a, yellow anchors) was performed. Next, the Root Mean Square Error (RMSE) and the predictive skill [14] were computed for the same stations, following the methodology proposed by Sousa and Dias and Dias et al., [15,16]. The comparison between harmonic constants computed from model predictions and observations was another quantification method used to perform the model accuracy assessment. This methodology was applied in this study, comparing the harmonic constants for the major tidal constituents in the Rias Baixas (M_2, S_2, K_1 and O_1) for the stations shown in (Figure 1a), determined using the Mat Lab® T-Tide package [17].

Predicted and observed salinity and water temperature were visually compared to evaluate the transport model accuracy, and RMSE and predictive skill were also determined to assess the model's accuracy. These comparisons were performed for two locations inside the rias (Figure 1a, blue buoys).

Climate change effects on the aquaculture production

To assess the impact of climate change on the aquaculture sector of the Rias Baixas, the locations of the aquaculture platforms on each of the three studied rias were obtained and represented on the three numerical grids. The two simulations described above were made, one referring to the past (1995-2005) and another concerning the future (2090-2100). Horizontal salinity and water temperature fields were predicted for both scenarios, for periods of 10 years. Then the mean value of each of these variables was calculated for each node of the numerical grids, and the differences between both scenarios results assessed.

Results

Numerical model assessment

The comparison between SSE numerical predictions and observations shows that the numerical model reproduces the observed records with high accuracy. The mean values obtained for RMSE and skill are 0.049 m and 0.992, respectively.

The phase and amplitude differences determined by harmonic analysis for numerical predictions and observations are shown in table 1. The distributions of both observed and predicted amplitude and phase are very similar. At all stations, M_2 presents a smaller phase difference, comprised between 0.090 to 1.6 min. The maximum amplitude difference for this constituent is observed at Ria de Pontevedra, with a value of 0.014 m. In general, it is verified that the best model predictions were obtained for the Ria of Arousa. The lower quality results were obtained for the Ria de Pontevedra, where was found the largest phase difference, 23.6 min for O_1 constituent, and the largest amplitude difference (for S_2). Comparing the accuracy of model predictions for the Ria de Vigo with that of a previous implementation by Sousa [18], a better representation of the dynamics of this system was found for the model implemented in the present work, considering the best fit obtained for all the harmonic constituents. Accordingly, it was assumed that the numerical application developed in this work reproduces with high quality and precision the tidal propagation along the Rias Baixas.

Regarding the salinity and water temperature predictions, the model adequately reproduces the variability of the thermo haline properties of the Ria de Vigo, presenting maximum RMSE values of 0.96ºC for water temperature and of 1.52 for salinity. For the Ria de Arousa, the RMSE values presented are higher than those obtained for the Ria de Vigo (1.61ºC for water temperature and 3.16 for salinity), in line with the results obtained by Sousa [18]. Following these results, it was concluded that the numerical model developed accurately reproduces the heat and salt transport inside the Rias Baixas.

Station	Constituent	Phase Difference (°)	Amplitude Difference (m)
Vigo	M_2	0.0687	0.0101
	S_2	0.7072	0.0232
	1	5.4716	-0.0029
	K_1	-2.7848	-0.0041
Pontevedra	M_2	0.778	0.0142
	S_2	2.3057	0.03
	1	5.4163	-0.0027
	K_1	-1.6258	-0.0076
Arousa	M_2	-0.0441	0.012
	S_2	0.3671	0.0257
	1	4.4633	-0.0014
	K_1	-1.8397	-0.0041

Table 1: Harmonic constants difference (phase and amplitude) for numerical predictions and observations.

Impact of climate change in the aquaculture sector of the Rias Baixas

The distribution of the mussel's mortality can be very sensitive to changes in water temperature and salinity, which are strongly dependent on changes in river discharges and ocean water intrusion. Thus, it is essential to assess the climate change impact on hydrologic estuarine patterns. (Figures 2 and 3) show maps of model predicted salinity and water temperature for the RCP 8.5 scenario for past and future simulations, respectively, Taking into account the location of aquaculture platforms current water temperature and salinity conditions are in the best ranges to obtain the highest growth rate, presenting the ideal values for mussel production. However, for the future they reveal that an increase of about 3ºC is expected for Rias Baixas water temperature, while a decrease of about 1 unit of salinity is forecasted. Based on results obtained by Gazeau et al., [19], the mussels are highly sensitive to a 3ºC warming, which may lead to suboptimal and even lethal temperature levels. Most of the extension of the three rias will present salinities ranging between 32 and 34, although are well-identified three areas where salinity levels range from 30 to 32. These areas coincide with the location of aquaculture platforms, and therefore should be considered very sensible for future aquaculture exploitation. They are located in the Ria de Arousa near the Umia river, and in the Ria de Vigo next to the Oitavén-Verdugo river (this area has the highest density of polygons) and finally in the Ria de Pontevedra next to the Lérez river. Therefore, for the future, in order to minimize the impact of climate change it will be important to change the locations of these platforms for the most suitable areas where salinity ranges remain ideal for mussel production. Regarding water temperature (Figure 3), maximum value reaches 21ºC.This looks to be a low value, but in fact should be considered normal as results from the annual averages of the temperatures numerically predicted for each grid element. Figure 3 shows three areas where values above 20ºC are found, and consequently where is predictable a decrease in growth rate for mussel. This species present the highest growth rates at temperatures ranging between 10ºC and 20ºC [9] and increased mortality rates when water temperature exceeds 25ºC [8]. Once again, these areas are in the Ria de Arousa, one next to the Umia River and the other next to the Ulla River, and in the Ria de Vigo next to the Oitavén-Verdugo river. Taking into account these results, it is important to change the platforms located in these areas to most suitable areas to ensure aquaculture exploitation. However, increasing temperatures and heat wave frequency can cause stress and mortality in marine organisms, affecting the local economy. Recruitment and seed production present possible bottlenecks for shellfish aquaculture in the future since early life stages are vulnerable to warming.

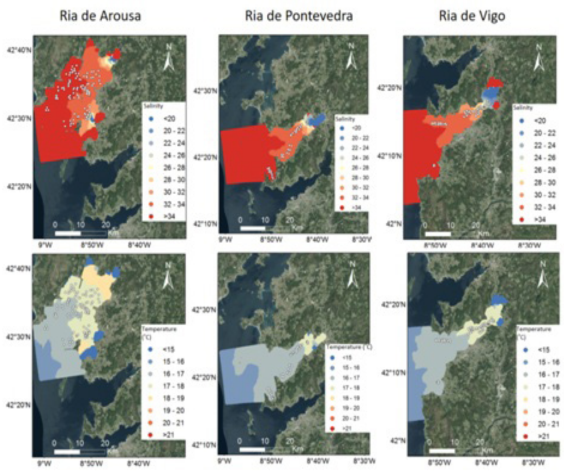

Figure 2: Salinity (upper pannel) and water temperature (lower pannel) horizontal maps averaged from 1995-2005 for Ria de Arousa, Ria de Pontevedra and Ria de Vigo.

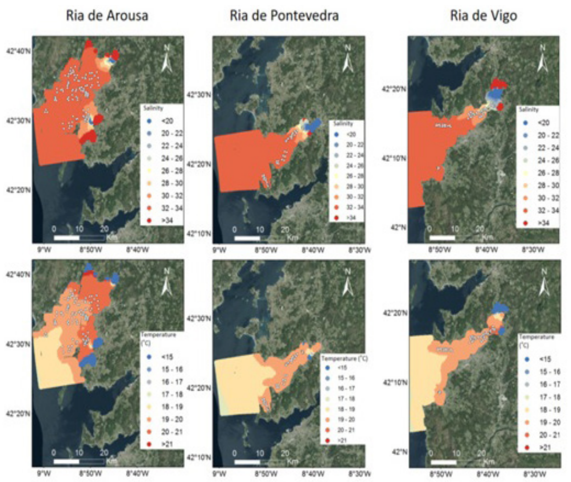

Figure 3: Salinity (upper pannel) and water temperature (lower pannel) horizontal maps averaged from 2090-2100 for Ria de Arousa, Ria de Pontevedra and Ria de Vigo.

Conclusion

The results obtained with this preliminary study show that climate change will endanger the aquaculture sector of the Rias Baixas, affecting the high level of actual mussels' production. The results suggest that ongoing ocean warming will be a serious threat to mussel production in these areas since it is predictable an increase of 3ºC in water temperature and a decrease 1 unity in salinity. Ria de Arousa and Ria de Vigo will be the most threatened, since the aquaculture platforms are installed in places where the predicted changes in both salinity and water temperature move away from the ideal range for mussels growth (between 10ºC and 20ºC). The Ria de Pontevedra will be the least affected, considering that in this coastal system only salinity will decrease to values below the critical range.

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References

1. Miranda L, Castro B, Kjerfve B (2002) Princípios de Oceanografia Física de Estuários. Edusp - Editora da Universidade de São Paulo, Brazil. Pg no: 424.
2. Pérez-Camacho A (1987) El cultivo de1 mejillon (*Mythsedulis*) y la ostra (*Ostreaedulis*) en España. In: Verreth JAJ, Carrillo M, Zanuy S, Huisman EA (eds.). Investigation Acuicolaen America Latina. Pudoc, Wageningen. Pg no: 243-260.
3. Pérez-Camacho, Gonzalez R, Fuentes J (1991) Mussel culture in Galicia (N. W. Spain). Aquaculture 94: 263-278.
4. European Commission (2013) European Maritime and Fund Fisheries. Economic performance and employment, Spain.
5. Pérez-Camacho A, Labarta U, Vinseiro V, Fernández-Reiriz M.J (2013) Mussel production management: Raft culture without thinning-out. Aquaculture 406-407: 172-179.
6. Martínez GM, Campos AO, Vilar EG, Pérez-Arlucea M (2011) Changes induced by mussel raft aquaculture in benthic environment of the Rías Baixas (Galicia, Spain). Journal of Coastal Research 64: 786-789.
7. Duarte P, Labarta U, Fernández-Reiriz MJ (2008) Modelling local food depletion effects in mussel rafts of Galician Rias. Aquaculture 274: 300-312.
8. Anestis A, Lazou A, Portner HO, Michaelidis B (2007) Behavioral and metabolic, and molecular stress responses of marine bivalve Mytilusgalloprovincialis during long-term acclimation at increasing ambient temperature. Am J Physiol Regul Integr Comp Physiol 293: 911-921.
9. Van Erkom Schurink C, Griffiths CL (1992). Physiological energetics of four South African mussel species in relation to size, ration and temperature. Comparative Biochemistry and Physiology 101: 779-789.
10. Smietanka B, Zbawicka M, Wolowicz M, Wenne R (2004) Mitochondrial DNA lineages in the European populations of mussels (Mytilus spp.). Marine Biology 146: 79-92.
11. Ferreira JF, Magalhães ARM (2004) Cultivo de mexilhoes. In: Poli CRP, Poli, ATB, Andreatta ER, Beltrame E (eds.). Aquicultura: experiencias brasileiras. Universidade Federal de Santa Catarina, Florianopolis, Brazil. Pg no: 221-250.
12. Kennedy VS, Twilley RR, Kleypas JA, Cowan Jr JH, Hare SR, et al. (2002) Coastal and Marine Ecosystems and Global Climate Change. ShoreNet: Beach, Shore, and Coastal Management Information. Pg no: 64.

13. Hanson RB, Alvarez-Ossorio MT, Cal R, Campos MJ, Roman M, et al. (1986) Plankton response following a spring upwelling event in the Ria de Arosa, Spain. Mar Ecol Prog Ser 32: 101-113.

14. Warner JC, Geyer WR, Lerczak JA (2005) Numerical modeling of an estuary: A comprehensive skill assessment. Journal of Geophysical Research-Oceans 110.

15. Sousa MC, Dias JM (2007) Hydrodynamic model calibration for a Mesotidal lagoon: the case of Ria de Aveiro (Portugal). Journal of Coastal Research 50: 1075-1080.

16. Dias JM, Sousa MC, Bertin X, Fortunato AB, Oliveira A, et al. (2009) Numerical modeling of the impact of the Ancão Inlet relocation (Ria Formosa, Portugal). Environmental Modelling & Software 24: 711-725.

17. Pawlowicz R, Beardsley B, Lentz S (2002) Classical tidal harmonic analysis including error estimates in MATLAB using T-TIDE. Computers & Geosciences 28: 929-937.

18. Sousa MC (2013) Modelling the Minho River plume intrusion into the Rias Baixas. PhD Thesis, Universidade de Aveiro, Aveiro, Portugal,166 pp.

19. Gazeau F, Alliouane S, Bock C, Bramanti L, Correa ML, et al. (2014) Impact of ocean acidification and warming on the Mediterranean mussel (*Mytilus galloprovincialis*). Frontiers in Marine Science.