International Congress on Environmental Modelling and Software

5th International Congress on Environmental Modelling and Software - Ottawa, Ontario, Canada - July 2010

Jul 1st, 12:00 AM

Bio-economic effects of water shortages on shellfish farming. An integrated dynamic modelling approach

J. A. Pérez Agúndez

Johanna Ballé-Béganton

Rémi Mongruel

Cédric Bacher

O. Le Moine

See next page for additional authors

Presenter/Author Information
J. A. Pérez Agúndez, Johanna Ballé-Béganton, Rémi Mongruel, Cédric Bacher, O. Le Moine, P. Soletchnik, S. Robert, and S. Guesdon

International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Bio-economic effects of water shortages on shellfish farming. An integrated dynamic modelling approach

J.A. Pérez Agúndez [a], J.Ballé-Béganton [a], R. Mongruel [a], C. Bacher [b], O. Le Moine [c], P. Soletchnik [c], S. Robert [c] and S. Guesdon [c]

[a] *Département d'Economie Maritime, IFREMER, BP 70, Plouzané, France (jose.perez@ifremer.fr)*

[b] *Département DYNamiques de l'Environnement Côtier, IFREMER, France*

[c] *Laboratoire Environnement Ressources des Pertuis Charentais, IFREMER, France*

Abstract: The land-sea interfaces are geographical areas rich in ecosystemic services. However, the increase of anthropogenic pressures is frequently the factor explaining environmental damages phenomena and generating many use conflicts. The integrated coastal zones management has been acknowledged by the different environment international conferences as a sustainability framework. Integration is the key concept on which must be based the reformulation of scientific knowledge required for supporting sustainable governance. That directly questions on the pertinent methods and tools to build for contributing to those decision making processes.

This paper explores these topics by focusing on the example of the fresh water share in the Charente river catchment in France. More concretely, we will focus on the consequences of the fresh water availability for the shellfish farming sector during the summer period. Fresh water represents the main means of nutrients transportation and a salinity regulator of the estuarine water masses. Both mechanisms can have effects on the recruitment and growth of cultivated animals. Using an integrative platform of dynamic modelling, the objective of this paper is (1) to build a model integrating relationships between the water hydrodynamics at the Charente watershed scale, the bio-economy of the shellfish farming activity, the internal use competition for fresh water and the external forcing of the system; (2) to assess the economic impacts supported by the shellfish farming sector linked to environmental modifications represented by the associated cost (or benefices) related to gaps between economic performances and productive production functions initially targeted and (3) to propose prospective scenarios of sustainable management trajectories supported by simulation procedures. All modelling developments will be assured by the ExtendSim numerical modelling platform

***Keywords**: modelling, water management, IZCM, shellfish farming, use conflicts*

1. INTRODUCTION

The coastal zones are generally areas rich in natural resources and supporting different ecosystem services. They increasingly attract many anthropogenic activities leading to more environment pressures, user conflicts and sustainability failures. The analysis of this paper are developed in the European SPICOSA FP6 project which aims to provide an holistic research approach for integrated assessment of Coastal Systems in support to sustainability by implementing Integrated Coastal Zone Management (ICZM) policies (Cicin-Sain , 1993, UNESCO, 2001, Christie, 2005). Complexity of assessments is managed by a holistic systematic modelling based on an oriented-problem approach taking into account the interactions between the components of the system and its resulting dynamics (Weide, J. van der., 1993). The study site application of the Charente catchment in the Atlantic coast, one of the 18 sites studied in the Spicosa project (***www.spicosa.eu***), has been chosen to test the modelling platform developed. The core issue analysed in this paper is the sustainable fresh water allocation as a main political question treated in the local political agenda. This common resource is the support of many ecosystem services. However, the catchment presents large hydrological variability and its water flow generally decreases sharply in summer when water demand is the highest (Labbé et al., 2000). This processes lead to water scarcity, drying out of some parts of the catchment and, conflicts between water users, mainly between agriculture and shellfish farming (Bouba-Olga et al., 2006). Agriculture is an important economic activity at the territory while the local shellfish farming represents the first oyster production in France (Girard et al 2005) and in Europe. This economic weight gives to these activities an important local political representation.

The local water management plan regulates the fresh water uses by implementing technical mechanisms of monitoring and restrictions in case of shortage (Labbé et al., 2000). The allocation is determined by a hierarchical priority of satisfaction for the following needs: (1) for households consumption and tourists, (2) for ecological needs to guarantee a good ecological functioning of the coastal ecosystems (rivers, saltmarshes, nurseries, coastal water productivity), (3) as inputs for important sectors structuring the local economy, mainly irrigated agriculture and shellfish farming, for which freshwater represent an important supplier of nutrients for oyster growth (Raillard and Menesguen, 1994). This system is highly determined by external forces such as the increase of touristic demand, the higher agriculture specialisation in irrigated crops due to the high prices of maize and other irrigated crops and obviously the climate change that increases the risk of drought.

In this context, this model explores sustainable management options of freshwater allocation in the Charente catchment by integrating (i) the ecological structure of the basin by a hydrology module, (ii) farming and shellfish farming modules considering their economic and ecologic dimensions, (iii) a module of drinking water demand, and (iv) a governance module implementing rules and feed-backing to user behaviours. This paper only focuses on the assessment of economic impacts suffered by the shellfish farming sector due to fresh water availability. This sector is placed in the downstream part of the catchment and consequently the fresh water flowing in the oyster areas directly depend on the other upstream water uses. The objective of this paper is to structure the shellfish farming module in order to simulate the economic effects of the variability of freshwater availability. The connexions of the different modules (e.g. hydrology - primary production - shellfish farming blocks) are not calibrated yet. However, the modularity of this modelling system allows appraising and calibrating each component separately. In this application use of the model, temperature and chlorophyll *a* are used in this preliminary stage as the main inputs of the biologic sub-model for testing the shellfish farm block functioning. The modelling platform used in this work is the ExtendSim simulation software.

2. MODEL DESCRIPTION

2.1 The ExtendSim platform

The ExtendSim modular simulation platform is based on a structure comprising blocks that interact by functional links. It offers two ways of modelling: (i) by using standard pre-programmed blocks stored in different libraries or (ii) by building "custom" blocks in ModL language, close to C language. This second way of programming is more adapted for modelling of complex systems into a problem oriented approach using databases and integrating (not necessarily coupling) different dimensions and scales. Dynamics are generated by feedback loops endogenously determined or by concrete rules previously determined. The model can simulate different political options related to the local freshwater management. The model is structured by modular and hierarchical blocks. New processes (natural or anthropogenic) can be progressively added. The core block of the model is the hydrologic component which is able to calculate the river flow considering climatic conditions. This flow is modified by different uses, mainly by the irrigated agriculture and the domestic consumption. The remaining freshwater supports the needs of the shellfish farming sector, the aquatic ecosystem and the recreational activities. Figure 1 illustrates this system graphically.

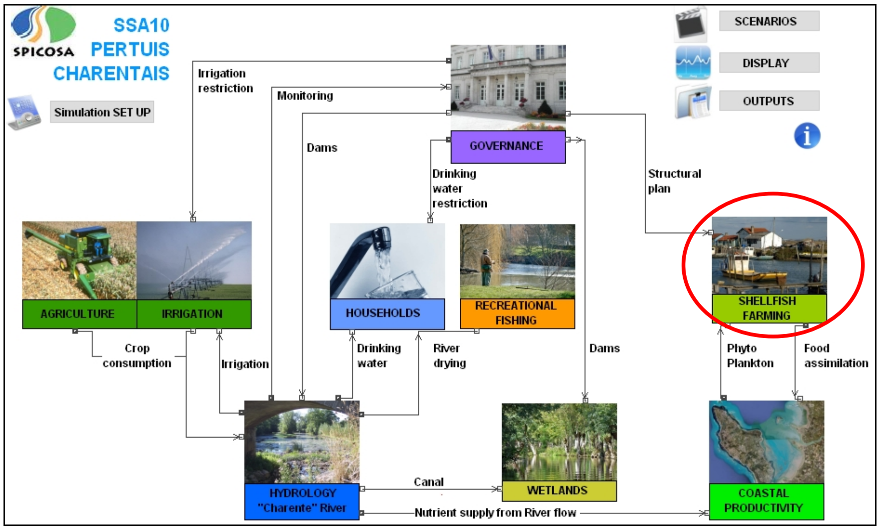

Figure 1: The global Extend water management model in the Pertuis Charentais region

Feedbacks from the "governance block" to users generate the dynamic of the system over time. The different scenarios built by a participatory process with stakeholders will explore the effect of those dynamics in order to support the knowledge required to improve the actual management processes. This paper focuses on the shellfish farming block to illustrate the methodology and the potential results, which can be obtained using the modular structure of the model.

2.3 The shellfish farming module

First developments of shellfish farming modelling have been focused on the decline of the shellfish farming performances related to trophic constraints (e.g.: Incze et al., 1981, Smaal et al., 1998). Later works have modelled the production dynamics linked to ecosystem forces and cultural practices (Raillard et Menesguen, 1994, Gagnery et al., 2004). Recently, more sophisticated models couple different ecosystem and economic dimensions (e.g: Nobre et al., 2009, Ferreira et al., 2007). The economic structure of those models is based on neoclassic microeconomic bases which consider competitive markets, price-takers producers, and profit maximization of companies. The modelling approach proposed in this paper concerns a larger systematic approach in which shellfish farming is one of the components of the model. The objective is (1) to explore dynamics of the global model and (2) to focus on the shellfish farming impacts after defining various scenarios. This module describes the biologic functioning of the shellfish farming activities which concern both production and trading. Production is partially constrained by the freshwater availability because it modifies the salinity of coastal waters and it supports nutrients required to generate the primary productivity. Trading is a complementary activity consisting in buying, conditioning and selling oysters. The weight of trading compared with production depends on the individual economic strategies of companies.

At this stage only a global model is considered with no individual information of shellfish farming companies. This can be justified by the fact that freshwater scarcity affects all companies at the same time and freshwater claims by the sector is collective. This module is structured by two main components described separately: the biologic production model and the economic adjustment procedures.

2.3.1 The biologic component of the model

The biologic component of the module concerns the coastal primary productivity (cf. figure 2) and the oyster population dynamics. The oyster growth is determined by several physical and ecological parameters which are modelled by a DEB (Dynamic Energy Budget) block. It describes the feeding and the energy stocking resources of oysters and their use for their main eco-physiologic functions (growth and reproduction). A simplified version of this model has been considered and only the growth function has been used. The generation of phytoplankton (nutrients for shellfishes) is conditioned by three main elements: the availability of nutrients (NO3), light and temperature. Nutrients are a state variable in the model determined by the NO3 concentration in the water masses and by the freshwater flow. An individual variability of growth determines a sub-cohort structure and improves the biomass output (Bacher et Gangnery, 2006). The equations and parameters are those developed from Kooijman, 2000), later validated for *Crassostrea gigas* by Pouvreau et al (2006), Bacher and Gangnery, 2006), using chlorophyll *a* concentration as food quantifier.

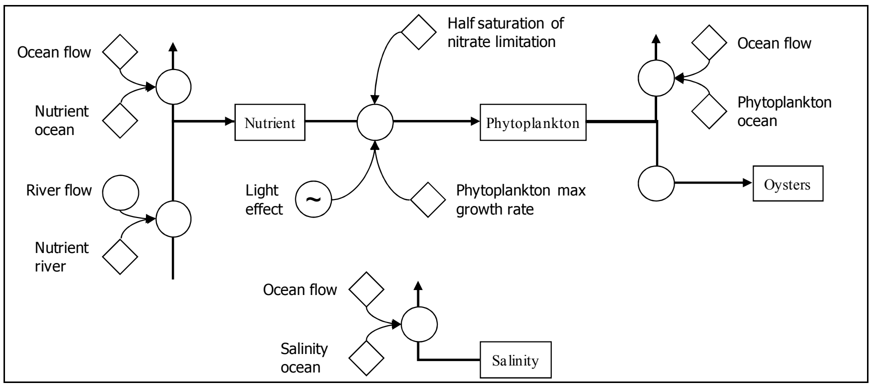

Figure 2: The conceptual model of coastal productivity

The coastal productivity, the oyster DEB sub-model and the population dynamics are mathematically detailed by the following equations:

$$dPhy/dt = PhyG \times Phy - OAF + Phy_{OceanExchange}, \quad (1)$$

$PhyG = PhyG_{max} \times LightEffect(t) \times [Nut / (Nut + K_{Nut})]$

- *OAF is calculated in the DEB Oyster Growth model* (2)
- $LightEffect(t) = Light_{Min} + (Light_{Max} - Light_{Min}) \times$
  $\times (1 + \cos(2p (t - Date_{MaxLight})/365) / 2$ (3)
- $Phy_{OceanExchange} = Ocean_{Flow} / Volume_{bay} \times Phy_{Ocean}$ -
- $(Ocean_{Flow} + River_{Flow}) / BayVolume \times Phytoplankton$

$$dNut / dt = - PhyG \times Phy + Nut_{RiverInput} + Nut_{OceanExchange} \quad (4)$$

- $Nut_{RiverInput} = River_{Flow} / Volume_{bay} \times Nut_{River}$ (5)
- $Nut_{OceanExchange} = Ocean_{Flow} / Volume_{bay} \times Nut_{Ocean}$ -
  $- (Ocean_{Flow} + River_{Flow}) / Volume_{bay} \times Nut$ (6)

$$dSal/dt = Ocean_{Flow} \times Sal_{Ocean} - (Ocean_{Flow} + River_{Flow}) \times Sal \quad (7)$$

$$dL / dt = DEBGrowth (L, T, Phy, Xk) \quad (8)$$

$$L (t_{Start}) = LengthGrowOutStart \quad (9)$$

- *DEBGrowth is calculated by the oyster DEB block*
- *LengthGrowOutStart is estimated to reach the target production*

$$dP / dt = - M \times P - Harvest_{Target} + TRD \quad (10)$$

$$P (t_{Start}) = PopulationGrowOutStart \quad (11)$$

- $Harvest_{Target}$ *-> Harvest is done seasonally and calculated to fulfill targeted production*
- *TRD is the number of animals traded (sales / purchases). It is an adjustment variable corresponding to the gap between the targeted and the current production*

Phy = phytoplankton, G = growth, OAF = oyster assimilation of food, Nt = nutrients, Sal = Salinity. L(length) and P (Population) are calculated for each sub-cohort; M= natural mortality rate, T = temperature; Xk = inter-cohort growth variability

The oyster population dynamics in the model is represented by cohorts (Nunes et at., 2003, Bacher and Gangnery, 2006) and sub-cohorts. The inter-cohort growth variability can highly modify the global output of companies (Gangnery et al., 2004). Each production process takes between 3 and 4 years. Therefore, several cohorts are simultaneously managed each period. Almost all sizes and cohorts, including marketable adult oysters are continuously available. At the beginning of each production cycle, the new cohort is supplied by spat collectors and complementary by hatcheries. A constant natural mortality parameter (10 %) has been considered (Raillard and Menesguen, 1994, Gangery et al., 2004).

2.3.2 The economic component of the model

The global production of the local shellfish farming companies reaches 30-35000 tons by year but they market 45-50000 tons. Companies "imports" oysters from other regions, mainly French. Some big companies are located in several shellfish farming basins and transfer oysters to the Charente basin from more productive areas. Trading activities represent a complement of revenues. Moreover, they are a key adjustment variable in case of low production performances. The model deals with a balance between the production dynamics and the economic adaptations that companies can implement, basically by commercial activities. The objective is to maintain, at least, constant revenues over time.

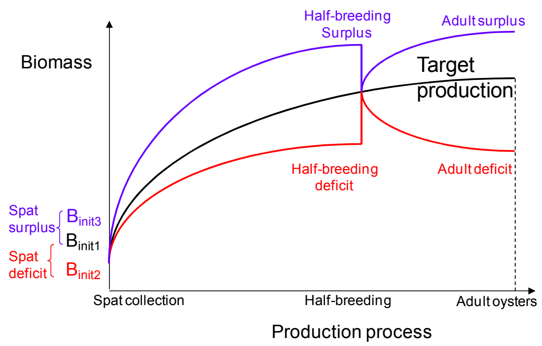

Figure 3: Scheme of the economic adjustments of shellfish farming companies into a complete production cycle

Companies are supposed to plan their global activity at the beginning of each production cycle by fixing a "target production function". This sort of reference represents the production level that companies can expect to reach considering their production functions (capital and labour constraints). This target function guides companies to adjust their activity depending on the production dynamics, considering environmental hazard. At the beginning of a cycle, knowing the growth and the mortality functions (by empirical retrospective observations) companies forecast the number of spat required for obtaining the oyster production targeted 3 years later. After this initial decision, ex-post changes of growth and mortality functions can drive to production gaps compared with the referent pattern. Companies can adjust their activity by two ways (cf. figure 3): (1) they can purchase animals in case of biomass deficit caused by high mortalities or by a low growth. In this case, adjustments lead to associated costs; (2) they can sell animals if favourable conditions cause a biomass overproduction. This second possibility generates associated revenues. These adjustments generally occur at three production stages: at the beginning of a cycle (spat), at the middle of a cycle (half-breeding animals) and at the end of a cycle (marketable adult animals). Mathematically, the economic deficit / surplus can be formulated as follows:

$$ES = [\, N^t \cdot W^t - \sum (\, N_{ij}^o \cdot W_{ij}^o \,)] \cdot \mathrm{P} \cdot \mathrm{e} \qquad (12)$$

ES is the economic surplus resulting from gaps between the targeted (t) and the current observed (o) production, N is the number of oyster and W their individual weight. Indices ij refer to cohorts "i" and sub-cohorts "j". P is the mean price of oysters and e is the elasticity price. This assessment is done at the three main production stages which are spat collection, half-breeding and final adult oysters. The model generates a database which describes the livestock structure and assesses if the global production of companies corresponds to the target production function. The gap /surplus of biomass related to this target production function multiplied by the market prices of animals determines the total

cost / revenues associated to this dynamics. The economic results of the shellfish farming sector, as other socioeconomic and environmental indicators from other blocks, will be considered in the governance block for simulating sustainable management scenarios.
Schematically, the Extend shellfish farming module work in broad outline as described below.

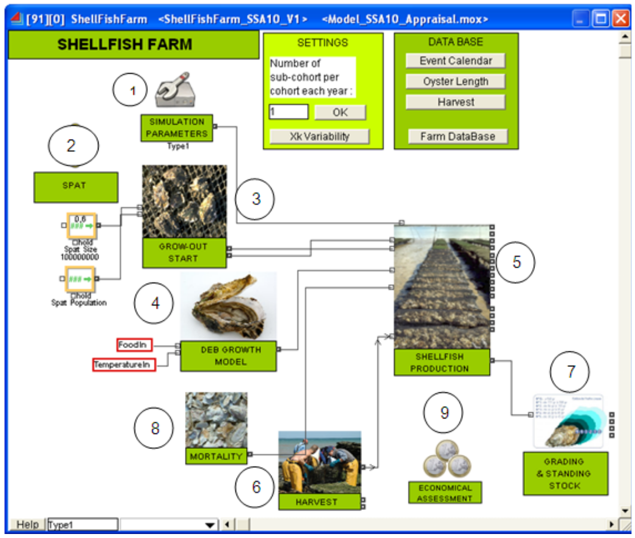

Figure 4: The shellfish farming module into the global water management model

(1) Sets all the ShellFish Farm simulation parameters: Database History tables, Sub-cohort numbers and Xk variability, (2) Estimation of initial value of spat depending on production target, (3) Grow-out start: at chosen date, inputs spat, oyster sub-cohorts, (4) DEB growth model: calculates the growth of oyster for each sub-cohort; (5) Calculates evolution of population and length of oyster sub-cohorts considering all modeled processes, (6) Calculates the total harvest of the sector by economic cycle and by season, (7) Calculates the biomass standing stocks and grades stock by weight for sale, (8) Mortality parameters (9) Economic assessment of shellfish farm gain or loss

3. MODEL CALIBRATION AND OUTPUTS

The objective of this preliminary work consists in structuring and calibrating the main processes of the shellfish farming module. At the beginning of the simulations, the stock biomass cultivated starts from zero and increases until reaching a stable level if there are no changes in the system. Oysters grow from the spat stage until the commercial size after 3 years. Inter-individual variability of growth produces several different sizes into each cohort. As a result, producers can offer a diversity of grades. The model deals with a number of oysters by sub-cohort and by size, but the biomass equivalent can be calculated any time.

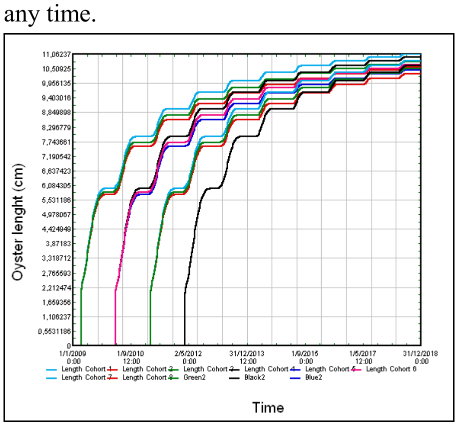

Figure 5: Simulation of oyster growth by cohort (using 3 sub-cohorts in the model)

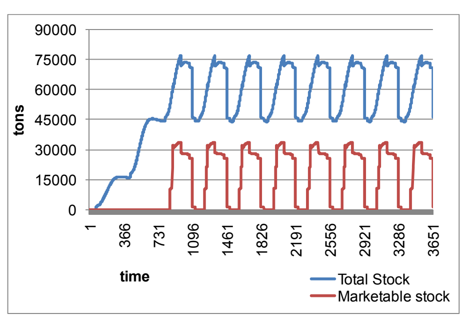

Figure 6: Estimation of the standing and the marketable stocks

One of the main technical operations of companies consists in recurrently grading oysters in order to control and manage their stocks Adult animals are graded in five commercial categories depending of their unitary weight: C5 (30-40 gr), C4 (46-65 gr), C3 (66-85 gr), C2 (86-110 gr), C1 (111-150 gr) and C0 (up to 150 gr). Too big animals or smaller than 30 gr are generally not marketable. There are no particular commercial sizes targeted by companies. The diversity of oyster sizes produced can satisfy different preferences of consumers. At each time step, the "grading block" of the model assesses the structural composition of the livestock cultivated, by cohort and by size. All individuals are "virtually" ranged in a database and a global balance can be made. Those operations are required by companies for adjusting their production and commercial activities to their economic objectives.

Considering the global production targeted by companies, the model calculates the eventual gaps of the current production if at least one of the following conditions operates: (1) if the spat collection is not sufficient for supplying producers and (2) if the oyster growth is lower than usual. Figure 7 shows that a dynamic considering only the production volume. At the beginning of the simulation companies present deficits until reaching the stable normal production cycles. Afterwards, if spat collection and growth are sufficient, considering normal environment conditions, companies are supposed to reach the production level targeted.

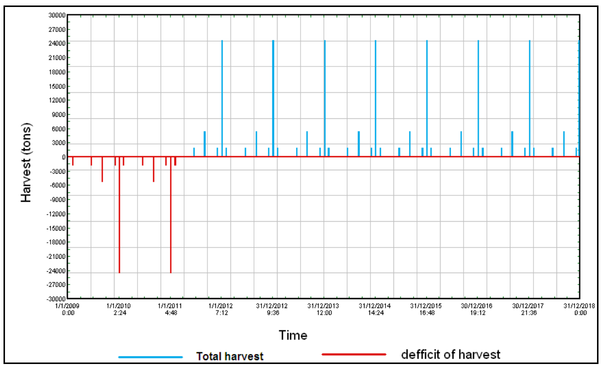

Figure 7: Economic balance of production of the global sector

At this development stage, economic balances are made each year considering different marketing seasons. The more important commercial period concerns Christmas (in which consumption of shellfish is part of the culinary traditions) and concentrates almost 50 % of the total annual revenue of companies. The importance of the other intra-annual commercial seasons depends on the demand and on the biologic processes of oysters. For instance, during reproduction, oysters are thinner and whitish and are generally not marketable. If no deficits are observed, the sum of production of all intra-annual seasons should be equal or higher than the global production initially targeted. In case of deficit the model considers no adjustment limitations and then companies can buy oysters to find again their targeted production trajectory (cf. figure 3). Associated costs or revenues will be calculated more accurately under new developments of the model considering the intra-annual seasons.

4. CONCLUSION AND DISCUSSION

This paper presents the main structure and the actual developments of a shellfish farming bio-economic module into an integrated freshwater management model. The main efforts were focused on structuring all the blocks of the system under a common interdisciplinary framework. The modular structure of the model represents a functional way for structuring and calibrating the internal processes of each module. An application to the shellfish farming module has been presented in this paper by formulating its different biologic and economic dimensions. Using sub-models and parameters of the literature, our model represents the bio-economic processes correctly. However, a more complete appraisal process will be required for calibrating the functional connexions between the shellfish farming, the hydrologic and the primary productivity blocks. The global results of the shellfish farming companies depend on this relationship chain.

The model estimates the annual surplus or deficits of shellfish farming companies by intra-annual seasons. However, real adjustments of companies occur into a multiannual production cycle (at the beginning, the half and the end of a cycle). New developments of this module will be required for moving from an intra-annual to a multi-annual frame integrating the historical dynamics of biomasses cultivated by cohort. The satisfaction of the shellfish farming sector can be measured by a binary indicator equal to 1 if companies globally reach their initial economic objectives and 0 otherwise. In the global model this indicator constitutes a determining factor to modify the freshwater allocation by the "governance block". Consequently, feedback effects to other blocks of the system can be derived from management changes due to shellfish farming claims. The ExtendSim platform is particularly well adapted to implement integrated assessments considering simultaneously outputs from all blocks and their different, ecologic and socioeconomic dimensions.

REFERENCES

Bacher, C.,Gangnery, A., 2006. Use of dynamic energy budget and individual based models to simulate the dynamics of cultivated oyster populations. Journal of Sea Research, Volume 56, Issue 2, August, Pages 140-155

Bouba-Olga, O., Chauchefoin, P., Mathé, J., 2006. Innovation et territoire : une analyse des conflits autour de la ressource en eau, Flux, n°63/64, 32-41.

Christie, P. 2005. Is integrated coastal management sustainable? Ocean and Coastal Management 48:208-232.

Cicin-Sain B., 1993.– Sustainable development and integrated coastal management. Ocean coast. Manag., no 21, p. 11 à 43, voir p. 27.

D. Brigolin, A. Davydov, R. Pastres, I. Petrenko, 2008. Optimization of shellfish production carrying capacity at a farm scale. Applied Mathematics and Computation, Volume 204, Issue 2, 15 October, Pages 532-540

Ferreira, J.G., Hawkins, A.J.S., Bricker, S.B., 2007. Management of productivity, environmental effects and profitability of shellfish aquaculture – the farm aquaculture resource management (FARM) model. Aquaculture 264, 160–174.

Gangnery, A., Bacher, C., Buestel, D., 2004. Modelling oyster population dynamics in a Mediterranean coastal lagoon (Thau, France): sensitivity of marketable production to environmental conditions. Aquaculture 230, 323-347.

Girard, S., Pérez Agúndez, J.A., Miossec, L., Czerwinski, N., 2001. Recensement de la conchyliculture 2001. Agreste Cah. 1, 89 pp.

Incze, L.S., Lutz, R.A., True, E., 1981. Modelling carrying capacity for bivalve molluscs in open, suspended-culture systems. J.World Maricult. Soc. 12, 143–155.

Kooijman, S.A.L.M., 2000. Dynamic energy and mass budgets in biological systems. Cambridge Univ. Press, Cambridge.

Labbé, F., Ruelle, P., Garin, P., et Leroy, P. (2000). Modeling irrigation scheduling to analyse water management at farm level during water shortages. European journal of agronomy 12: 55-67.

Nobre A.M., Musango J.K., Wit M.P. de, Ferreira J.G., 2009 A dynamic ecological–economic modeling approach for aquaculture management. Ecological Economics, Volume 68, Issue 12, 15 October 2009, Pages 3007-3017

Nunes, J.P., Ferreira, J.G., Gazeau, F., Lencart-Silva, J., Zhang, X.L., Zhu, M.Y., Fang, J.G., 2003. A model for sustainable management of shellfish polyculture in coastal bays. Aquaculture 219, 257–277.

Pouvreau, S., Bourles, Y., Lefebvre, S., Gangnery, A., Alunno-Bruscia, M., 2006. Application of a dynamic energy budget model to the Pacific oyster, Crassostrea gigas, reared under various environmental conditions. J. Sea Res. 56, 156–167

Raillard, O., Ménesguen, A., 1994. An ecosystem box model for estimating the carrying capacity of a macrotidal shellfish system. Mar. Ecol. Prog. Ser. 115, 117-130.

Smaal, A.C., Prins, T.C., Dankers, N. , Ball, P., 1998. Minimum requirements for modelling bivalve carrying capacity. Aquat. Ecol., 31, 423-428.

UNESCO, 2001. Des outils et des hommes pour une gestion intégrée des zones côtières. Guide méthodologique – volume II.

Weide, J. van der. (1993). "A Systems View of Integrated Coastal Management" in: Ocean and Coastal Management. Vol. 21, No. 1-3, pp. 129-148.