ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Modelling the biogeochemical cycle of the Oualidia lagoon (Atlantic, Morocco)

Zainab Damsiri[1,*], Khalid Elkalay[1], Karima Khalil[1].

Laboratory of Applied Sciences for the Environment and Sustainable Development, School of Technology
Essaouira, Cadi Ayyad University. Essaouira Al Jadida, Route d'Agadir, BP 383, Essaouira, Morocco.

Manuscript Info

Manuscript History:

Received: 15 December 2014
Final Accepted: 19 January 2015
Published Online: February 2015

Key words:
Modelling, Oualidia lagoon, phytoplankton, nutrients.

******Corresponding Author***

Zainab Damsiri

Abstract

Modelling nutrient cycle dynamics in the open ocean based on the well-known interactions among nutrients, phytoplankton, and zooplankton is well established and will be used in this work. Difficulty arises in applying this methodology to multiple coastal systems because of differences among geography, water chemistry, microbial interactions, weather patterns, and sedimentary nutrient cycling. Current trends in ecological modeling are toward more complex modeling relationships and mathematical functions. Preliminary comparisons with field data showed that the model reproduced realistic values. A sensitivity analysis was performed in order to identify the most sensitive variables of the model.This model will be easly able to reproduce most of the significant characteristics of the temporal variations of nutrients and of phytoplankton growth in the water surface of the Oualidia lagoon.

INTRODUCTION

Coastal lagoons are a very common feature of coastal environments occupying 13% of the world coastline (Barnes, 1980). They are ecosystems of ecologic, economic and social value and are especially sensitive to both anthropogenic and natural disturbances (Perilla et al., 2012). These environments are highly dynamic and controlled by physical processes, and subject to frequent environmental fluctuations (Pérez-Ruzafa et al., 2005) and the degree of isolation from marine waters (López, 2003). Most lagoons act as sinks for nutrients since evaporation exceeds freshwater input (Herrera-Silveira & Comin, 1995) and, in addition, they receive inputs of material from both the land and the atmosphere via deposition and microbial processes such as nitrogen fixation (Taylor, Nixon, Granger, & Buckley, 1995).

The importance of the construction of nutrient budgets and of flux-based analysis when dealing with the problems of coastal eutrophication can hardly be overestimated. To this regard, the development and application of numerical model can be regarded as an important tool for understanding the functioning of a coastal ecosystem, exploring its behavior and developing management strategies based on general principles (Hobbie, 2000; Skliris, 2000; Elkalay, 2003).

The case study is the Oualidia lagoon, an important coastal ecosystem in the Moroccan Atlantic that has been rarely investigate. In the Oualidia lagoon, oyster aquaculture and agriculture have a negative impact on water and sediment quality in this ecosystem. In spite of that, the Oualidia lagoon still hosts highly valuable typical habitats, as well as several economic activities that depend upon the ecosystem health, such as fisheries, recreational activities and tourism.

Several studies have been conducted in Oualidia lagoon, biology (Beaubrun, 1976; Chbicheb, 1996), hydrology (Orbi et al, 1998; Rharbi et al, 2001), Geology (Carruesco 1989; Fakir, 2001; El himer et al., 2013), sedimentology Sarf, (1999), quality and safety (Bennouna, 1999; Shafik et al., 1996; El Attar, 1998), currentology (Hilmi et al., 2005) and biogeochimical cycles (Damsiri et al., 2014a; 2014b; Natij et al., 2014). However, the modeling of the lagoon have not been the subject direct studies.

The model developed in this paper represents the first attempt at simulating the seasonal dynamics of the phytoplanktonic production in relation to the availability of dissolved nutrients, mainly nitrogen. Experimental data are used to set up and validate the model, which enables one to estimate the nutirents fluxes in the four compartments: the water column, the phytoplankton, the zooplankton and the detritus and to study the general interaction.The results, can be of help in understanding the ecosystem dynamics and providing suggestions for an environmentally correct planning of the above-mentioned intervention.

1. Model description

We use a general and typical model of the Moroccan Atlantic coast which we adapted to the specificity of the plankton ecosystem of the Oualidia lagoon. The state variables of this model are determined by the essential components of the Atlantic coastal ecosystems. These state variables are characterized by their lifestyles (autotrophic and heterotrophic) and their nature (inorganic or organic matter).

The components of the ecosystem are represented by compartments, and interactions are described by linking compartments (**Fig. 1**). The state variables are: Zooplankton (chaetognaths, cladocerans, microzooplankton, appendix and copepods), phytoplankton (diatoms, flagellates and picophytoplankton), ammonium ($\mu molN.l^{-1}$), nitrate ($\mu molN.l^{-1}$), particualte organic nitrogen (PON), dissolved organic nitrogen (DON), bacteria and silicate (**Table 1**). The major nutrient sources for plankton was the water column.

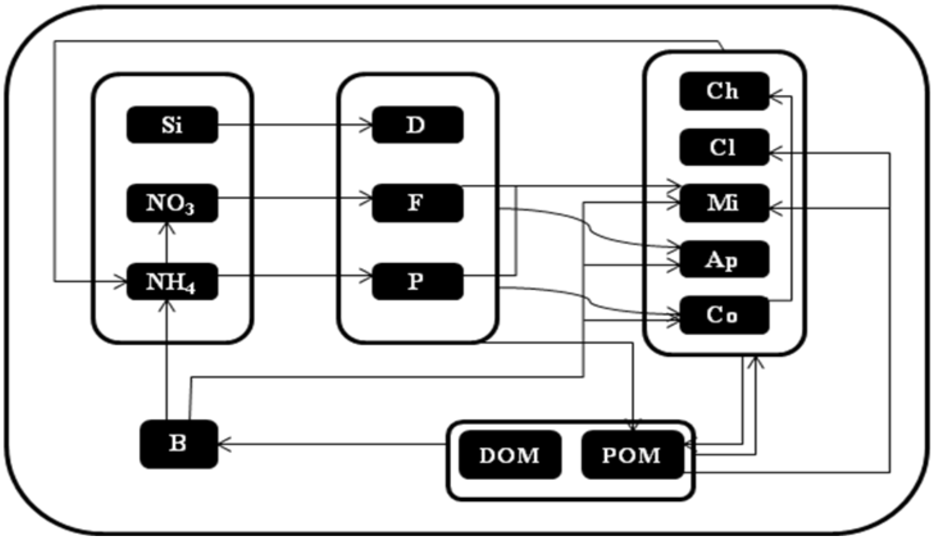

Figure 1: Block-diagram of the biological model. *State variables*: **NO_3**: nitrate; **NH_4**: ammonium; **Si**: Silicate; **D**: Diatoms; **F**: Flagellate; **P**: Picophytoplankton; **Ch**: Chaetognathes; **Cl**: Cladoceran; **Mi**: Microzooplankton; **Ap**: appendiceal; **Co**: copepods; **B**: Bacteria; **DOM**; **POM**: Dissolved and particulate organic matter respectively.

Table 1: Full equation for study models (**NO3**: Nitrate; **NH4**: ammonium; **D**: diatoms; **P**: picophytoplankton; **F**: flagellate; **Ap**: appendiculeal; **Cl**: cladoceran; **Mi**: microeooplankton; **Co**: copepods; **Ch**: chaetognaths; **B**: bacteria; **DON**: dissolved organic nitrogen; **PON**: particulate organic nirtrogen and **Si**: silicate).

$$\frac{\mathbf{dNO_3}}{\mathbf{dt}} = nit_{NH4}.\ \mathbf{NH_4} - \mu_{NO3D}.\ \mathbf{D} - \mu_{NO3P}.\ \mathbf{P} - \mu_{NO3F}.\ \mathbf{F}$$

$$\frac{\mathbf{dNH_4}}{\mathbf{dt}} = -\ nit_{NH4}\ .\ \mathbf{NH_4} - \mu_{NH4D}\ .\ \mathbf{D} - \mu_{NH4P}\ .\ \mathbf{P} - \mu_{NH4F}\ .\ \mathbf{F} - \mu_{NH4B}\ .\ \mathbf{B} + (1-ex_{NOD}).\ ex_{Ap}.\ \mathbf{Ap} + (1-ex_{NOD}).\ ex_{Cl}.\ \mathbf{Cl} + (1-ex_{NOD}).\ ex_{Mi}.\ \mathbf{Mi} + (1-ex_{NOD}).\ ex_{Co}.\ \mathbf{Co} + (1-ex_{NOD}).\ ex_{Ch}.\ \mathbf{Ch} + ex_{B}.\ \mathbf{B}$$

$$\frac{\mathbf{dD}}{\mathbf{dt}} = (1-exu_{D}).\ (\mu_{NO3D} + \mu_{NH4D}).\ \mathbf{D} - m_{D}.\ \mathbf{D} - br_{DCo}.\ \mathbf{Co} - br_{DAp}\ .\ \mathbf{Ap}$$

$$\frac{\mathbf{dP}}{\mathbf{dt}} = (1-exu_{P}).\ (\mu_{NO3P} + \mu_{NH4P}).\ \mathbf{P} - m_{P}.\ \mathbf{P} - br_{PCo}.\ \mathbf{Co} - br_{PAp}.\ \mathbf{Ap} - br_{PMi}.\ \mathbf{Mi}$$

$$\frac{\mathbf{dF}}{\mathbf{dt}} = (1\text{-}exu_{F}).\ (\mu_{NO3F} + \mu_{NH4F}).\ \mathbf{F} - m_{F}.\ \mathbf{F} - br_{FCo}.\ \mathbf{Co} - br_{FAp}.\ \mathbf{Ap} - br_{FMi}.\ \mathbf{Mi}$$

$$\frac{\mathbf{dAp}}{\mathbf{dt}} = as_{Ap}.\ (ing_{DAp} + ing_{FAp} + ing_{PAp}).\ \mathbf{Ap} - (m_{Ap} + ex_{Ap}).\ \mathbf{Ap} - br_{ApCh}.\ \mathbf{Ch}$$

$$\frac{\mathbf{dCl}}{\mathbf{dt}} = as_{Cl}.\ (ing_{MiCl} + ing_{NOPCl} + ing_{BCl}).\ \mathbf{Cl} - (m_{Cl} + ex_{Cl}).\ \mathbf{Cl}$$

$$\frac{\mathbf{dMi}}{\mathbf{dt}} = as_{Mi}.\ (ing_{FMi} + ing_{PMi} + ing_{BMi} + ing_{NOPMi}).\ \mathbf{Mi} - (m_{Mi} - ex_{Mi}).\ \mathbf{Mi} - brMiCl.\ \mathbf{Cl}$$

$$\frac{\mathbf{dCo}}{\mathbf{dt}} = as_{Co}.\ (ing_{Dco} + ing_{PCo} + ing_{Fco} + ing_{BCo} + ing_{NOPCo} + ing_{NODCo}).\ \mathbf{Co} - (m_{Co} - ex_{Co}).\ \mathbf{Co} - br_{CoCh}.\ \mathbf{Ch}$$

$$\frac{\mathbf{dCh}}{\mathbf{dt}} = asCh.\ (ing_{CoCh} + br_{SCh}).\ \mathbf{Ch} - (m_{Ch} + ex_{Ch}).\ \mathbf{Ch}$$

$$\frac{\mathbf{dB}}{\mathbf{dt}} = (\mu_{NH4B} + \mu_{NODB}).\ \mathbf{B} - (ex_{B} - m_{B}).\ \mathbf{B} - br_{BCl}.\ \mathbf{Cl} - br_{BMi}.\ \mathbf{Mi} - br_{BCo}.\ \mathbf{Co}$$

$$\frac{\mathbf{dDOM}}{\mathbf{dt}} = exu_{D}.\ (\mu_{NO3D} + \mu_{NH4D}).\ \mathbf{D} + exu_{P}.\ (\mu_{NO3P} + \mu_{NH4P}).\ \mathbf{P} + exu_{F}.\ (\mu_{NO3F} + \mu_{NH4F}).\ \mathbf{F} - \mu_{NODB}.\ \mathbf{B} - \mu_{NODD}.\ \mathbf{D} - dis_{NOP}.\ \mathbf{NOP} + ex_{NOD}.\ ex_{Ap}.\ \mathbf{Ap} + ex_{NOD}.\ ex_{Cl}.\ \mathbf{Cl} + ex_{NOD}.\ ex_{Mi}.\ \mathbf{Mi} + ex_{NOD}.\ ex_{D}.\ \mathbf{D} + ex_{NOD}.\ ex_{Ch}.\ \mathbf{Ch}$$

$$\frac{\mathbf{dPOM}}{\mathbf{dt}} = m_{D}.\ \mathbf{D} + m_{P}.\ \mathbf{P} + m_{F}.\ \mathbf{F} + m_{Ap}.\ \mathbf{Ap} + m_{Cl}.\ \mathbf{Cl} + m_{Mi}.\ \mathbf{Mi} + m_{Ch}.\ \mathbf{Ch} + m_{B}.\ \mathbf{B} - dis_{NOP}.\ \mathbf{NOP} - br_{NOPCl}.\ \mathbf{Cl} - br_{NOPMi}.\ \mathbf{Mi} - br_{NOPCo}.\ \mathbf{Co} + (1 - as_{Ap}).\ (ing_{DAp} + ing_{FAp} + ing_{PAp}).\ \mathbf{Ap} + (1 - as_{Cl}).\ (ing_{MiCl} + ing_{NOPCl} + ing_{BCl}).\ \mathbf{Cl} + (1 - as_{Mi}).\ (ingFMi + ing_{PMi} + ing_{BMi} + ing_{NOPMi}).\ \mathbf{Mi} + (1 - as_{Co}).\ (ing_{DCo} + ing_{PCo} + ing_{BCo} + ing_{NOPCo} + ing_{NODCo}).\ \mathbf{Co} + (1 - as_{Ch}).\ (ing_{CoCh} + ing_{SCh}).\ \mathbf{Ch}$$

$$\frac{\mathbf{dSi}}{\mathbf{dt}} = -(\mu_{NO3D} + \mu_{NH4D}).\ r_{SiN}.\ \mathbf{Si}$$

The phytoplankton growth is limited by the nutrients concentration, irradiance and temperature (Evan L. Turner, 2014) **(Table 2) (Table 3).** We assume that the nutrient limitation is controlled by the more limiting nutritive element, which is nitrogen in our case. We consider that the dissolved inorganic nitrogen consists of nitrate and ammonium in order to distinguish the new and regenerated production (Dugdale and Goering, 1967) and we use the function of (Wrob-lewski, 1977), to simulate the ammonium inhibition of the nitrate uptake by the phytoplankton. The functions of limitation by irradiance and temperature are defined by the formula of Peeters and Eilers, (1978).

Table 2: Processes and parameters used in the model

Process	Definition	Formulation
Phytoplankton		
μ_y	Growth rate	$\mu_{yx} = \mu_{maxy}.\ L_{Ny}.\ L_{ty}.\ L_{iy}$
μ_{yNO3}	Growth rate of NO_3	$\mu_{yNO3} = \mu_{maxy}.\ L_{NO3}.\ L_{ty}.\ L_{iy}\ .\ L_{SiD}$
μ_{yNH4}	Growth rate of NH_4	$\mu_{yNH4} = \mu_{maxy}.\ L_{NH3}.\ L_{ty}.\ L_{iy}\ .\ L_{SiD}$
L_{Ny}	Limitation by nitrogen	$L_{Ny} = L_{NO3y} + L_{NH4y}$
L_{NO3y}	Limitation by NO_3	$= \frac{NH_4}{k_{yNH4} + NH_4}\ e^{-\theta . NH_4} + \frac{NO_3}{k_{yNO3} + NO_3}$
L_{NH4y}	Limitation by NH_4	
L_{SID}	Limitation of diatoms by Si	$L_{SID} = \frac{Si}{k_{SiD}+Si}$
L_{ty}	Limitation by temperature	$L_{ty}=2(1+\beta_{ty})\ (x_T/x_T^2+2\beta_{ty}\ x_T+1)$ $x_T=(T-T_{ly})/(T_{oy}-\ T_{ly})$
L_{ly}	Limitation by irradiance	$L_{ly}=2(1+\beta_{ly})\ (x_l/x_l^2+2\beta_{ly}\ x_l+1)$
Zooplankton		
br_{ij}	Biomass potentially catchable prey	$br_{ij} = V.\ eff_{ij}.\ Y$
eff_{yx}	Capture efficiency of prey i by predator j	
V	Explored volume	$V = \frac{ing_j}{B_j}$
Y	Prey concentration	$B_j = \sum_{i=1}^{n} eff_{ij}.Y$
Ing_i	Rate of Ingestion i	If $B_{ij} \leq b_{0j}$ alors $ing_j = 0$ If $B_{ij}>b_{0j}$ alors $ing_j=ing_{maxj}\ (\frac{B_{yx} - b_{0j}}{B_{yx} + b_{0j} + k_j})$
n	Number of prey for a predator	
i	index of prey	
j	index of predator	
b_{0j}	maximum threshold for nutrition i	
ex_{zoo}	excretion of zooplankton	$ex_{zoo}=a_y\ b_y^T$
Bacteria		
μ_B	Growth rate of bacteria	$\mu_{bac} = \mu_{BNOD} + \mu_{BNH4}$
μ_{BDON}	Utilization rate of NOD	$\mu_{BDON} = \mu_{maxB} \frac{DON}{k_B + S + DON}$
μ_{BNH4}	Utilization rate of NH_4	$\mu_{BNH4} = \mu_{maxB} \frac{S}{k_B+S+NOD}$
μ_{maxB}	Maximum growth rate of bacteria	
S	Substrate concentration of nitrogen	$S = \min\ (NH_4,\ \eta DON)$

Zooplancton is described by five state variables, which are representative of the pool of species that prey upon the phytoplankton and microzooplakton. Grazing is described by a relationship (M. Mateus, 2012; Frangoulis, 2002), while mortality, exudation and respiration of both phytoplankton and zooplankton are described as first order-processes **(Table 2) (Table 4a, 4b and 4c)** the kinetic constants exponentially increase with water temperature.

Table 3: Parameters values of the phytoplankton growth. (**D**: Diatoms; **F**: flagellate; **P**: picophytoplankton). **wd**: without dimension. 1: Andersen et Rassoulzadegan, (1991); 2: Chifflet et al. (2001); 3: Kumar et al. (1991); 4: Fasham et al. (1990); c: calibration**.**

Symbol	Parameters	Units	Values			Ref
			D	**F**	**P**	
μ_{maxy}	Maximal growth rate	j^{-1}	2	2.5	3	1
k_{yNH4}	Half-saturation coefficient for NH_4	μmolN l^{-1}	1	0.7	0.7	2
k_{yNO3}	Half-saturation coefficient for NO_3	μmolN l^{-1}	2	1	1	2
θ	Inhibition coefficient by NH_4	$(\mu molN\ l^{-1})^{-1}$	1.462	1.462	1.462	3
β_{iy}	Photo-inhibition coefficient	wd	-0.6	-0.7	-0.8	1
I_{ov}	Optimal irradiance	μE m^{-2} s^{-1}	250	300	360	2
β_{ty}	Thermo-inhibition coefficient	wd	-0.55	-0.5	-0.5	1
T_{lv}	Low lethal temperature	°C	9	9	9	1
T_{ov}	Optimal temperature	°C	16	15	15	1
m_v	Mortality rate	j^{-1}	0.06	0.05	0.06	c
ex_y	Percentage autotrophic exudation	%	4	5	6	4

Table 4a: Growth, excretion and mortality parameters of zooplankton. (**Ch**: Chaetognaths; **Cl**: Cladoceran; **Mi**: Microzooplankton; **Ap**: Appendiceal; **Co**: Copepods). **wd**: without dimension. 1. Chapelle et al. (2000); 2. Fasham et al. (1990); 3. Andersen et Rassoulzadegan, (1991); 4. Lèvy et al. (1998); 5. Conover, (1966) in Chapelle et al. (2000); c. calibration.

Symbol	Parameters	Units	Values					Ref
			Ap	**Cl**	**Mi**	**Co**	**Ch**	
ing_{maxj}	Maximum ingestion rate	j^{-1}	1.3	1.9	1.8	0.96	1.7	c,1
b_{0j}	Minimum threshold for ingestion	μmolN l^{-1}	0.01	0.01	0.03	0.03		c
k_j	Half-saturation coefficient for ingestion	μmolN l^{-1}	0.5	1	0.75	0.75	1	c,2
as_y	Assimilation rate of Y	wd	0.65	0.8	0.7	0.9	0.8	4,5,c
m_y	Mortality	j^{-1}	0.03	0.05	0.05	0.04	0.035	3,2,c

Table 4b: Parameters values of capture efficiency of zooplankton. **D**: Diatoms; **F**: Flagellate; **P**:Picophytoplankton; **Ch**: Chaetognaths; **Cl**: Cladoceran; **Mi**: Microzooplankton; **Ap**: Appendiceal; **Co**: Copepods; **B**: bacteria; **DOM** and **POM** of dissolved and particulate organic matter respectively. Efficiency without dimension.

Symbol	Parameters	Values				
eff_{yAp}	Capture efficiency Y by Ap	**D** 0.5	**P** 0.2	**F** 0.7	**B** 0.2	
eff_{yCl}	Capture efficiency Y by Cl	Mi 0.7	POM 0.2			
eff_{yMi}	Capture efficiency Y by Mi	B 0.3	P 0.8	F 0.7	POM 0.2	
eff_{yCo}	Capture efficiency Y by Co	P 0.25	F 0.9	D 0.7	DOM 0.2	POM 0.2

eff_{yCh}	Capture efficiency Y by Ch	Ap 0.9	Co 1

Table 4c: Parameters values excretion for zooplankton. 1. Andersen et Razoulzadegan (1991); c calibration. (**Ch**: Chaetognathes; **Cl**: Cladocerans**; Mi**: Microzooplankton; **Ap**: Appendiceal; **Co**: Copepods).

		Ap	**Mi**	**Co**	**Cl**	**Ch**	Ref
a_y	Excretion rate at 0 °C	0.067	0.1	0.086	0.076	0.076	1,c
b_y	Slope factor for the excretion curve	1.050	1.05	1.031	1.045	1.045	1,c

The main sources of ammonium and nitrate are agricultural, oyster inputs, leaching watershed, excretion heterotrophs and mineralization by bacteria from the dissolved organic matter or organic debris. Nutrient limitation is represented by the Michealis-Menten functions. The nitrogen cycle is forced by the temperature and irradiance. The particulate organic matter (POM) consists of fecal pellets and detritus. Note that the dissolved organic matter (DOM) is formed by two very different processes.
The first one, is the exudation of phytoplankton. The second is a decomposition of particulate organic matter.

Bacteria incorporate the dissolved organic matter and ammonium. In fact, the bacteria get their carbon from the dissolved organic matter and are capable of assimilating ammonium when not have sufficient nitrogen for the synthesis of their proteins (Evan L. Turner, 2014; Fasham et al., 1990). Bacteria incorporation will be assumed to the Michaelis-Menten relationship while taking into account the two possible sources of nitrogen according to the proposed model Fasham et al. (1990) **(Table 2) (Table 5).**

We assum that total substrate nitrogen available for bacteria as the minimum between the ammonium concentration and the dissolved organic matter corrected using the report assimilation NH_4/DON estimated to 0.6. The formulation proposed by these authors (Fasham et al., 1990) intake of ammonium corresponding to 60% of the dissolved organic matter, as long as there is enough available ammonium. Otherwise, taking the nutrients (ammonium and DON) will be reduced together. The Michaelis kinetics which describes the incorporation of NH_4 by bacteria is characterized by a high absorption speed and a very low half-saturation constant. In the sea, the small phytoplankton is able to compete with the bacteria. We assume that all that is assimilated by the bacteria is used for growth (Fasham et al., 1990; Moloney and Field, 1991).

Table 5: Parameters values for bacteria. 1. Andersen et Rassoulzadegan, (1991); 2. Fasham et al. (1990); 3. Lèvy et al. (1998). **wd**. without dimension.

Term	**Parameters**	**Units**	**Values**	**Ref**
μ_{Bmax}	Maximum growth of bacteria	j^{-1}	2	1
k_B	Half-saturation coefficient	µmolN l^{-1}	0.5	2
η	Assimilation report NH_4/DON	wd	0.6	2
asB	Assimilation rate	wd	1	3
m_B	Mortality rate	j^{-1}	0.06	1,2

Results and discussion

The versatility of the model allows to perform different simulation experiments. In this paper, part of the results are presented as an example of how insights can be derived from this model.

Temperature and irradiance

Our result produce correctly a good correlation between simulated and observed temperature values (**Fig. 2**), in the surface water. Comparison of the model predictions with *in-situ* measurements showed a good accordance. Figure 3 gave the simulated irradiance at the surface water.

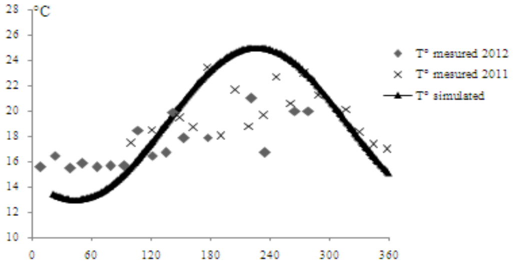

Figure 2: Simulated and observed temperature values (**T°**)

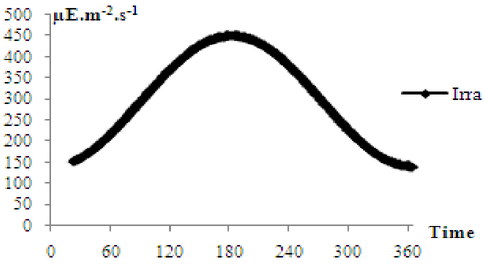

Figure 3: Simulated irradiance values (**Irra**)

Phytoplankton

Figure 4 showed the temperature limitations of the growth of diatoms and dinoflagellate in the surface water. The dinoflagellate and diatoms had the same growth limitations by temperature (**Fig. 4**). The growth limitations of the diatoms by temperature were more important than dinoflagellate. The lowest limitations were noted at the beginning of the simulation in surface and decreased with time (June and July), but the higher limitations were registered in Octobre.

An intake of nitrate were resgistered in February (**Fig. 5a**), with a wintry mix. The nitrate concentration was decreased in April until August and then increase again. The values recorded of ammonium in the water surface, are significant at the begnning of the year (**Fig. 5a**). During May-June, the ammonium concentration keeps relatively high values (0.25 µmolN l^{-1}) with time.

The first biomass peak of diatoms (**Fig. 5b**) and flagellates (**Fig. 5c**) was noted in January, early February. These species had a short flowering early in the simulation. The phytoplankton bloom was in March with a maximum between (0.3 and 0.6 µmolN l^{-1}). The diatoms bloom begins in surface and with time follow nitrates concentrations. Flagellates had another peak during June-July, with a maximum biomass of 0.25 µmolN l^{-1}.

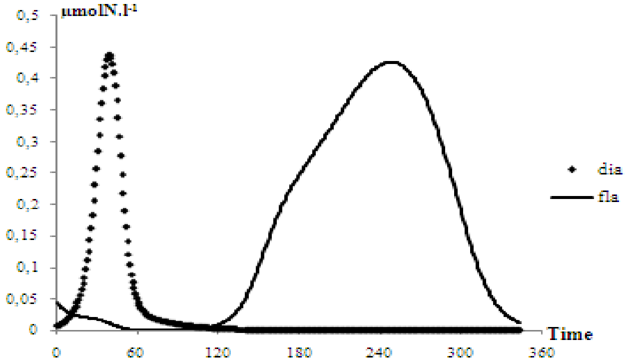

Figure 4: Temperature limitation of diatoms (**dia**) and dinoflagellates (**fla**) growth in the surface water.

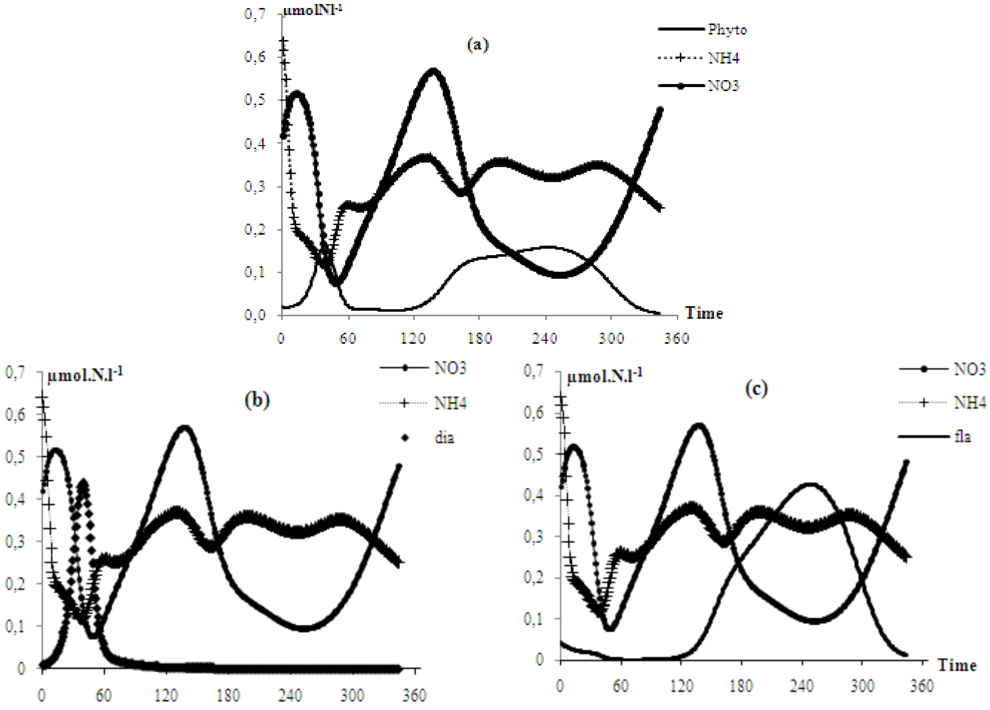

Figure 5: Simulated evolution of nutrients (**NH4, NO3**) and phytoplankton (**Phyto**) (**a**), nutrients (**NH4, NO3**) and diatoms (**dia**) (**b**) and nutrients (**NH4, NO3**) and flagellates (**fla**) (**c**).

Zooplankton

The first blooms of diatoms and flagellates were followed by an appendiceal and copepods (**Fig. 6a**) with a maximum of 0.06 and 0.5 µmolN l^{-1} respectively. The second copepods and appendiceal bloom was simulated in April, with a maximum of 0.35 µmolN l^{-1} and 0.02 µmolN l^{-1} respectively.

Microzooplankton (**Fig. 6b**) was presented in February with a maximum following 0.5 µmolN l^{-1}, with a significant ingestion of bacteria beginning of the year. The second peak (0.4 µmolN l^{-1}) of microzooplankton was enregistered in April, following a development of flagellates. Another peak in mid-June was enregistered (0.35 µmolN l^{-1}).

Cladocerans (**Fig. 6c**) begin to develop from March with low concentrations (0.06 µmolN l^{-1}) distributed throughout the water column, this biomass increased during May with a maximum of 0.25 µmolN.l^{-1} deep in August.

The Chaetognaths (**Fig. 6d**) develop after copepods, which explains the first bloom in late January with a maximum overestimated biomass of 0.3 µmolN l^{-1}. A second development occured a maximum of biomass (0.12 µmolN l^{-1}) in May. The biomass of chaetognath decreased in time. All zooplankton species disappear in autumn because their growth is probably not sufficient to excced the predation, excretion and mortality losses.

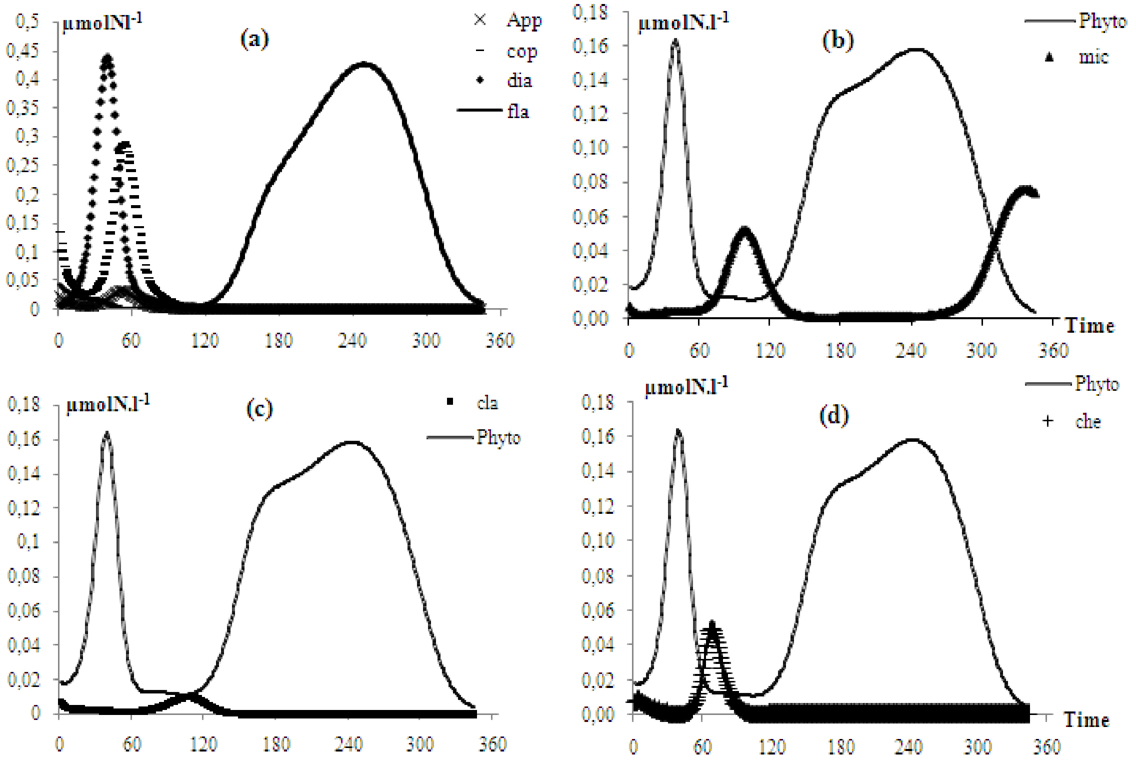

Figure 6: Simulated evolution of zooplankton and phytoplankton biomass (Appendiceal: **App**, Copedods: **cop**, diatoms: **dia** and flagelate: **fla (a)**, phytoplankton: **Phyto** and microzooplankton: **mic (b)**, Cladoceran: **Cla** and phytoplankton: **Phyto (c)** and phytoplankton: **Phyto** and Chaetognathes: **che (d)**).

Organic matter

Bacteria (**Fig. 7**) were observed throughout the year, they had the important development (1.05 µmolN l^{-1}) from February. Biomass were elevated throughout the summer following the highest concentrations of dissolved organic matter and ammonium.

The concentration of particulate organic matter (**Fig. 7**) increased in January and had a large surface to the first peak in April and a second in June. The dissolved organic matter concentration (**Fig. 7**) was 0.14 µmolN l^{-1} at the beginning of the year. Two peaks was observed, the first one (0.18 µmolN l^{-1}) in April and the second (0.22 µmolN l^{-1}) in August. The dissolved organic matter distribution was following the particulate organic matter and zooplankton in summer.

Phytoplankton and zooplankton blooms were well simulated by the model, but it was impossible reproduce all the details of the nutrients evolution, for all simulations. The highest concentrations noted in the summer could be explained by the zooplankton excretion equation, which is set in this model as a temperature function. It would be interesting in the process using a formulation that takes into account the diet of zooplankton groups (M. Mateus,

2012) (Frangoulis et al., 2001). Another source of error could come from the parameters values. At the beginning of the seasonal cycle, the spring phytoplankton bloom occured after fertilization and in winter was the annual maximum biomass and production. Phytoplankton was dominated by a few species with high growth rate optimally utilizing the mineral reserves. The Herbivores were abundant but poorly diversified and dominated by macrozooplankton. The Microzooplankton was presented but little diversified. Following the spring plankton bloom, the diatoms report: dinoflagellates strongly reduced in favor by this group of diatoms.

In mid-summer to early winter, temporarely increases the diversity by the small flagellates and picophytoplanktons groups. The lowest biomass of zooplankton was in summer. Mainly the microzooplankton, limited to a few small carnivorous copepods and cladocerans carnivores feeding of microzooplankton (Hecq, 2001). The maximum total phytoplankton biomass simulated (1.05 µgchl a l^{-1}). The maximum zooplankton biomass simulated (90 µg PS l^{-1}). The report N/Chla was considered constant for the three groups of phytoplankton. However, can be varied by irradiance, temperature and by the nutrient concentrations (eg Cloern et al. 1995), as well as the time (Chifflet et al. 2001). To improve this model version, the N/Chla report could be considered for each species and variable according the time (Touratier, 1996) and the model's sensitivity to these variations should be reviewed. We can also changes to our model, (eg. the distinction between the different phases of development in the same species of zooplankton). The modelling of such processes requires the development of a sub-model of population dynamics. The idea of co-limiting of the production by the primary phosphates and nitrogen, in relation to trophic conditions appears reasonable. However, the use of two elements in the same model involves the use of the relationship between these two elements to move from one unit to another. It would be interesting to use the N/P ratio for each species with the change in time and space (Touratier et al., 2001. Omlin et al., 2001b).

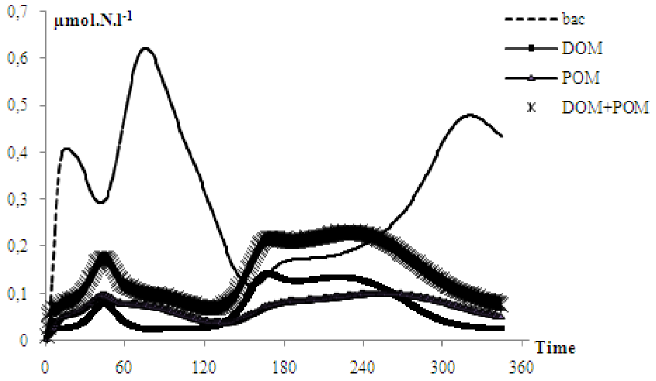

Figure 7: Simulated between bacteria (**bac**) and organic matter concentration (**DOM** and **POM**).

Sensitivity analysis study

Sensitivity analysis study was realised in order to estimate the relative effect of initial conditions of the state variables, forcing constraints and parameters values variations.

Three variables from the analysis were more sensitive to the parameters variations were ammonium, chaetognaths and appendiceal. For three variables respectively (90, 89 and 96 of 102 in total), almost all parameters cause variations of the model superior to 1%. In our model the parameter variations does not exceeding 2% for chaetognaths, 3% for ammonium and, 4% for appendiceal. The state variables nitrates and diatoms were particularly stable.

Figure 8, showed the effect of initial conditions variations on the model. Only four variables ammonium, copepods, cheatoghnathe and PON were sensitive to the parameters variations (>1%). Generally the initial variations conditions had a sensitivity index lower than 5% compared to simulation reference. Appendiceal variable seemed to be the most sensitive and had two sensitivity indices higher than 4% corresponding to DON and cladocerans (with indices 4.55% and 4.15% respectively). Three sensitivity indices for NH_4 higher than 2% caused by initial conditions of flagellates, NH_4 and NO_3. The chaetognaths variable was influenced by a one variable (appendicle) with 2% index. The copepods was sensitive only to changes in initial values of NH_4 and NO_3, they had less than 2%. The diatoms and silicate were less influenced by variations of the initial conditions.

Our model was relatively resistant to the variations to initial conditions. The sensitivity analysis presented in our study does not account for the fact that the sensitivity of the model to the variation of a single variable at a time and a "standard" variation of ± 20% for all variables. It would be interesting to use the Monte-Carlo analysis to asses the standard deviation of the simulation average by treating a large number of simulations where the parameters were varied. This technique is still very costly in terms of simulation time.

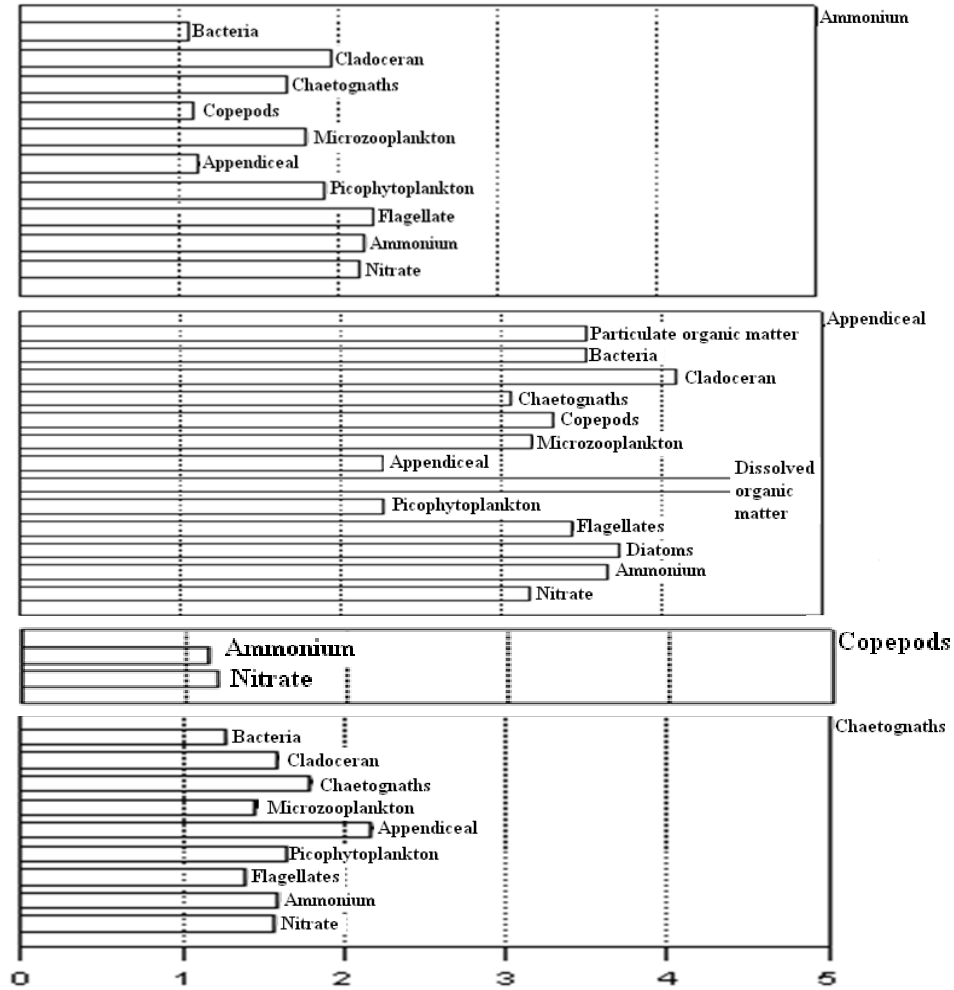

Figure 8: Sensitivity analysis of initial conditions for each state variable (**Ammonium, Appendiceal, Copepods and Chaetognaths**). Only parameters with greater than 1% indices are presented.

Conclusion

Our model correctly reproduces the main features of the evolution of different variables. Decreasing the concentration of diatoms and flagellates after the first months of simulation and was following by the increase in biomass picophytoplankton. The model reproduce the succession of planktonic events. In spring a phytoplankton, followed by the zooplankton bloom. The simulations revealed some weaknesses of the model. Nutrient cycling is not well described. We should develop some processes, such as absorption by phytoplankton and heterotrophic excretion. Our model seems quite suitable for diagnostics that we want to establish for the Oualidia lagoon, although simplifications are significant to its more widespread use. The overall conclusion of the sensitivity analysis, some parameters are very sensitive, such as those related to the process of heterotrophic excretion. This finding is not negative, as the same sensitivity of these parameters strongly constrains their estimate in a calibration procedure. However, it emphasized the need for regular enough data for this procedure. Generally, the uncertainty of the model response is almost exponential function of its complexity, given the non-linearity of the evolution equations.

The specificity of each ecosystem requires a recalibration of parameters through experiences that reflect local conditions. Full validation of this model over several years and in various metrological conditions should be the next step for improvement. It seems interesting to use this typical and general model to study the Moroccan lagoons taking as cases our study area (Oualidia lagoon), by reducing the number of state variables according to data availability.

References

-Amanieu, M., Legendre, P., Trousselier, M., & Frisoni, G. F. (1989): Le programme Ecothau: theorie ecologique et base de la modelisation. Oceanologica Acta, 12, 189-199.

-Andersen, V., Rassoulzadegan, F. (1991): Modèle vertical de l'écosystème pélagique. Réseau microbien et sédimentation des particules biogeniques. J. Rech. Océanogr. 16(1-2), 16-22.

-Barnes, R. S. K. (1980): Coastal lagoons. Cambridge: Cambridge University Press.

-Bennouna, A. (1999): Etude du phytoplancton nuisible et de son environnement dans la lagune de Oualidia et de Sidi Moussa (Maroc). Thèse de Doctorat 3ème Cycle, Faculté des Sciences, El Jadida, 153 p.

-Beaubrun, P.C. (1976): Les huîtres au Maroc et l'ostréïculture dans la lagune de Oualidia. Bull. Inst. Pêches Maritimes. Casablanca. 22, 13-143.

-Bendoricchio, G., Coffaro, G., & De Marchi, C. (1994): A trophic model for the Ulva rigida in the lagoon of Venice. Ecological Modelling, 75/76, 485-496.

-Bougis, P. (1974): Écologie du Plancton Marin. Tome I: Le phytoplancton. Masson et C^{ie} Éditeurs. Collection d'écologie 2. 196 p.

-Brohée, M., Goffart, A., Frankignoulle, M., Henri, V., Mouchet, A., Hecq, J.H. (1989): Variations printanières des communautés planctoniques en baie de Calvi (Corse) en relation avec les contraintes physiques locales. Cah. Biol. Mar. 30, 321-328.

-Carruesco, C. (1989): Genèse et évolution à l'holocène de trios lagunes de la façade atlantique : Moulay Boussaleham, Oualidia et Arachon (France). Thèse doctorat d'état. Es science université de border. n°9602 (tomes 2), 2005, 485 p.

-Chafik, A., Cheggour, M., Rharbi, N., Bouhallaoui, A. (1996): Evaluation de la salubrité de la lagune de Oualidia : étude de la contamination métallique de l'huître creuse Crassosteras gigas. Travaux et Documents INRH, N° 93, Institut National de Recherche Halieutique, Maroc.

-Chapelle, A., Ménesguen, A., Deslous-Paoli, J.M., Souchu, P., Mazouni, N., Vaquer, A., Millet, B. (2000): Modeling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters framing and inputs from the watershed. Ecol. Model. 127, 161-181.

-Chapelle, A. (1995): A preliminary model of nutrient cycling in sediments of a Mediterranean lagoon. Ecological Modelling, 80, 131-147.

-Chapelle, A., Mesnage, V., Mazonni, N., Deslous-Paoli, J. M., & Picot, M. (1994): Modelisation des cycles de l'azote et du phosphore dans les sediments d'une lagune soumise a une exploitation conchylicole. Oceanologica Acta, 17, 609-620.

-Chbicheb, A. (1996): Organisation bio géologique d'un bassin paralique : La lagune d'Oualidia (côte atlantique marocaine). Thèse de Doctoart. Univ. de NANTES.

-Chifflet, M., Andersen, V., Prieur, L., Dekeyser, I. (2001): One-dimensional model of short-term dynamics of the pelagic ecosystem in the NW Mediterranean sea: effects of wind events. J. Mar. Syst. 30, 89-114.

-Cioffi , F., Di Eugenio, F., & Gallerano, F. (1994): Simulation models for forecasting anoxic crisis in lagoons. In P. Zannetti (Ed.), Computer techniques in environmental studies, Billerica, MA: Pollution Modelling, Vol (1), 107-120.

-Cloren, J.E., Grenz, C., Vidergar-Lucas, L. (1995): An empirical model of the phytoplankton chlorophyll: carbon ratio the conversion between productivity and growth. Limnol. Oceanogr. 7, 1310-1313.

-Conover, R.J. (1966): Assimilation of organic matter by zooplancton. Limnol. Oceanogr. 11, 338-345.

-Damsiri Zainab, Natij Laila, Khalil Karima, Loudiki Mohamed, Rabouille Christophe, Ettahiri Omar, Bougadir Belaid, Elkalay Khalid. (2014a): Spatio-temporal nutrients variability in the Oualidia lagoon (Atlantic Moroccan coast). International journal of advanced research, Vol (2), Issue 8, 609-618.

-Damsiri Zainab, Laila Natij, Khalid Elkalay, karima khalil, Mohamed Loudiki. (2014b): Etude comparative sur les lagunes marocaines (Méditerranée, Atlantique). Scienlib, Vol. 6(140701).

-Dejak, C., Mazzei Lalatta, I., Meregalli, L., & Pecenik, G. (1987): An advection-diffusion pollution model for the Lagoon of Venice. Ecological Modelling, 37, 47-57.

-Lazure, P. (1992): Etude de la dynamique de Petang de Thau par modele numerique tridimensionnel. Vie Milieu, 42, 137-145.

-Dugdale, R.C., Goering, J.J. (1967): Uptake of new and regenerated forms of nitrogen in primary productivity. Limnol. Oceanogr. 12, 179–184.

-El Attar, J. (1998): Contribution à la détermination de l'origine de la contamination fécale dans la lagune de Oualidia (Maroc) et étude de la contamination bactériologique de l'huître « Crassostera Gigas » en conditions naturelles et expérimentales. Thèse de 3ème Cycle. Faculté des Sciences, El Jadida, 124 p.

-El Himer, H., Fakir, Y., Stigter, T. Y., Lepage, M., El Mandour, A & Ribeiro, L. (2013): Assessment of groundwater vulnerability to pollution of a wetland watershed: The case study of the Oualidia-Sidi Moussa wetland, Morocco. Aquatic Ecosystem Health & Management, 16(2): 205–215.

-Elkalay Khalid, Frangoulis Constantin, Skliris Nikos, Goffart Anne, Gobert Sylvie, Lepoint Gilles, Hecq Jean-Henri. (2003): A model of the seasonal dynamics of biomass and production of the seagrass *Posidonia oceanica* in the Bay of Calvi (Northwestern Mediterranean). Ecological Modelling 167, 1–18.

-Eppley, R.W. (1972): Temperature and phytoplankton growth in the sea. Fish. Bull. 70, 1063–1085.

-Evan L. Turner, Denise A. Bruesewitz, Rae F. Mooney, Paul A. Montagna,James W. McClelland, Alexey Sadovski, Edward J. Buskey. (2014): Comparing performance of five nutrient phytoplankton zooplankton (NPZ) models in coastal lagoons. Ecological Modelling 277, 13–26.

-Fakir, Y. (2001): Contribution à l'étude des aquifères côtiers: Cas du Sahel de Oualidia (Province de Safi – Maroc). Thèse de Doctorat d'Etat Es-Science. Univ. Cadi Ayyad, 143p.

-Fasham, M.J.R., Ducklow, H.W., Mckelvie, S.M. (1990): A nitrogen-based model of plankton dynamics in the oceanic mixed layer. J. Mar. Res. 48, 591-639.

-Frangoulis, C. (2002): Mesozooplankton outfluxes in coastal areas. Thèse de Doctorat. Université de liège. Belgique. 220 p.

-Frangoulis, C., Belkhiria, S., Goffart, A., Hecq, J.H. (2001): Dynamics of copepod faecal pellets in relation to a *Phaeocystis* dominated phytoplankton bloom: characteristics, production and flux. J. Plankton Res. 23, 75-88.

-Gato, M., Laniado, M., & Rossi, R. (1982): The management of eels in the Vali di Comacchio lagoon. Oceanologica Acta Special Vol., Actes Symposium International sur les Lagunes Cotieres, SCOR/IAB0/UNESCO, 303-307

-Goffart A., Hecq, J.H., Prieur, L. (1995): Contrôle du phytoplancton du basin ligure par le front liguro-provençal (secteur corse). Oceanol. Acta, 18, 329-342.

-Hecq, J.H. (2001): Une modélisation conceptuelle et numérique de l'écosystème planctonique océanique. Thèse d'agrégation de l'enseignement supérieur. Université de Liège. 299 p.

-Hecq, J.H., Gaspar, A., Dauby, P. (1981): Caractéristiques écologiques biochimiques de l'écosystème planctonique en baie de Calvi (Corse). Bull. Soc. Roy. Sci. Liège, 50, 440-445.

-Herrera-Silveira, J. A., & Comin, F. A. (1995): Nutrient fuxes in a tropical coastal lagoon. Ophelia, 42, 127-146.

-Hilmi, K., Koutitonsky, V.G., Orbi, A., Lakhdar, J.I., Chagdali, M. (2005): Oualidia lagoon: an estuary without a river. Afr. J. Aquatic Sci. 30(1) 1-10.

-Hobbie, J.E. (Ed.). (2000): Esutarine Science: a Synthetic Approach to Research and Practice, 539p.

-Kumar, S.K., Vincent, W.F., Austin, P.C., Wake, G.C. (1991): Picoplankton and marine food chain dynamics in a variable mixed-layer: a reaction-diffusion model. Ecol. Model. 57, 193-219.

-Laila Natij, Zainab Damsiri, Karima Khalil, Mohammed Loudiki, Omar Ettahiri, Khalid Elkalay. (2014): Phytoplankton abundance and diversity in the coastal waters of Oualidia lagoon, south Moroccan Atlantic in relation to environmental variables. International Journal of Advanced Research, Vol (2), Issue 6, 1022-1032.

-Levy, M., Memery, L., André, J.M.(1998): Simulation of primary production and export fluxes in the Northwestern Mediterranean Sea. J. Mar. Res. 56, 197-238.

-Moloney, C.L., Field, J.G. (1991): The size-based dynamics of plankton food webs. I. A simulation model of carbon and nitrogen flows. J. Plan. Res. 13(5), 1003-1038.

-Ivlev, V.S. (1955): Experimental Ecology of the Feeding of Fishes. Yale Univ. Press (1961)., New Haren, 302 p.

-Lasserre, P. (1981) : Biological approach to coastal lagoons: Metabolism and physiological ecology. Coastal lagoon research present and future (Unesco Technical Papers in Marine Sciences, Vol. 33). Seminar Proceedings, Dulce Univ. Mar. Lab, Beaufort, NC, USA, August 1978.

-López, P. (2003): Effects of changes in water salinity on ammonium, calcium, dissolved inorganic carbon and influence on water/sediment dynamics. Estuarine, Coastal and Shelf Science. 56, 943-956.

-M. Mateus. (2012): A process-oriented model of pelagic biogeochemistry for marine systems. Part I: Model description. Journal of Marine Systems 94, S78–S89.

-Omlin, M., Brum, R., Reichert, P. (2001a): Biogeochemical model of Lake Zurich: sensitivity, identifiability and uncertainty analysis. Ecol. Model. 141, 105-123.

-Omlin, M., Reichert, P., Forster, R. (2001b): Biogeochemical model of Lake Zurich: model equations and results. Ecol. Model. 141, 77-103.

-Orbi, A., Hilmi, K., Larissi, J., Zidane, H., Zizah, S., El Moussaoui, N., Lakhdar, J.I., Sarf, F. (1998): Hydrologie et hydrodynamique des côtes marocaines : milieux paraliques et zones côtières. Commissariat général Expo'98, Lisbonne, 68 p.

-Nixon, S. W. (1982): Nutrient dynamics, primary production and ®shery yields of lagoons. Oceanologica Acta Special Vol., Actes Symposium International sur les Lagunes Cotieres, SCOR/IABO/UNESCO, 357-381.
-Parsons, T.R., Lebrasseur, R.J., Fulton, J.D. (1967): Some observations on the dependance of zooplankton grazing on cell size and concentration of phytoplankton blooms. J. Oceanogr. Soc. Jpn. 23, 10-17.
-Perilla, OLU., Gómez, AG., Díaz, CA., Cortezón, JAR. (2012): Methodology to assess sustainable management of water resources in coastal lagoons with agricultural uses: an application to the Albufera lagoon of Valencia (Eastern Spain). Ecological Indicators. 13, 129-143.
-Pérez-Ruzafa, A., Fernández, A.I., Marcos, C., Gilabert, J., Quispe, JI., García- Charton, JA. (2005): Spatial and temporal variations of hydrological conditions, nutrients and chlorophyll a in a Mediterranean coastal lagoon (Mar Menor, Spain). Hydrobiologia. 550, 11-27.
-Platt, T., Gallegos, C.L., Harrison, W.G. (1980): Photoinhibition of photosynthesis in natural assemblages of marine phytoplankton. J. Mar. Res. 38, 687-701.
-Peeters, J.H.H., Eilers, P. (1978): The relationship between light intensity and photosynthesis in natural assemblages. A simple mathematical model. Hydrobiol. Bull. 12, 134-136.
-Rharbi, N., Ramdani, M., Berraho, Ab., Lakhdar, J.I. (2001): Caractéristiques hydrologiques et écologiques de la lagune de Oualidia : milieu paralique de la côte atlantique marocaine. Marine Life 11(1-2) 3-9.
-Rhee, G.Y. (1978): Effects of N:P atomic ratios and nitrate limitation on algal growth cell composition, and nitrate uptake. Limnol. Oceanogr. 23, 10-25.
-Sarf, F. (1999): Dynamique sédimentaire et état de pollution de la lagune de Oualidia. Thèse de 3ème Cycle. Faculté des Sciences, Rabat, 121 p.
-Skliris, N., Elkalay, K., Goffart, A., Frangoulis, C., Hecq, J.H., 2000. One-dimensional modelling of the plankton ecosystem of the north-western Corsican coastal area in relation to meteorological constraints. J. Mar. Syst. 27, 337-362
-Taylor, D. I., Nixon, S. W., Granger, S. L., & Buckley, B. A. (1995): Impacts of different forms of nutrients on the roles of coastal lagoons as nutrient sources or sinks-a mesocosm study. Ophelia, 42, 353-370.
-Touratier, F., Field, J.G., Moloney, C.L. (2001): A stoichiometric model relating growth substrate quality (C:N:P ratios) to N:P ratios in the products of heterotrophic release and excretion. 139, 265-291.
-Touratier, F. (1996): Modélisation écologique en région septentrionale de la Mer du Nord: application à la campagne de mesures du Fladen Ground 1976 (FLEX'76). Thèse de doctorat, Université de Liège, 302 p.
-Wroblewski, J. (1977): A model of phytoplankton plume formation during variable Oregon upwelling. J. Mar. Res. 35, 357-394.