NEW UNIVERSITY OF LISBON

Faculty of Sciences and Technology

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OYSTERS RETURN TO THE TAGUS ESTUARY

THROUGH AN ECOLOGICAL MODEL

By

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Abstract

Aquaculture is an activity that has been increasing along the last years. Until the 1970's Portugal and more specifically the Tagus estuary, was the major exporter of oysters in Europe. Factors like TBT and oysters gill disease had made that the shellfish aquaculture has never been again practised in Tagus estuary. According to that, this work intends to concept and to implement an ecological model that develops the oysters growth in order to them return to the estuary. To begin with, the model was calibrated with data from Database of 1980 and then validated with Database of 1982. The model results have shown a good correlation with measured data, so it was supposed as a good model.

After that, it was simulated two different scenarios. The first one it was increased 3^0C in water temperature and in the second one it was changed the seeding day to the 90 day instead the 120 day. The results illustrate that in scenario I, the production of oysters decrease as well as the oyster individual weight and length, and in scenario II, however the oyster individual growth as decrease a little the oyster total harvest as increase.

With these approaches, it will be possible to define the better conditions in order to achieve a good model that can be able to optimise the production of oyster in the Tagus estuary.

Keywords: *Crassostrea angulata*; Bivalves; Ecological model; Tagus estuary; Portugal.

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1. Introduction

1.1. Problem definition

This work aims to create another alternative to fisheries economy. Over the last decades, our fish stock has been decreasing. With aquaculture, it is possible to reverse this situation.

The Tagus estuary has been chosen for this study because it provides the conditions to implement the aquaculture of bivalves, as existed for decades, until the collapse 35 years ago of the fishery of the Portuguese oyster *Crassostrea angulata*.

It was developed an ecological model, which integrated the physical and biogeochemical processes as well as population dynamic conditions for the oyster's growth. This model can estimate the carrying capacity of this place.

1.1.1. Aquaculture worldwide

World aquaculture has grown considerably during the last fifty years. In the 1950s the production was less than a million tonnes and in 2004 it was 59.4 million tonnes, of which 69.6% were accounted for by China, 21.9% by Asia (excluding China) and the Pacific, 3.5% by the Western Europe, 2.3% by Latin America and the Caribbean, 1.3% by North America, 0.9% by Near East and North Africa, 0.4% by Central and Eastern Europe and 0.2% by Sub-Saharan Africa. The sector has grown at an average of 8.8% per year since 1970 (FAO, 2006).

According to FAO (2001), shellfish and finfish aquaculture also has grown significantly over the last two decades. The first one, perhaps, is the most sustainable form of mariculture because it is largely extensive, requiring no artificial food input and because the animals obtain all their nutrition from phytoplankton, microphytobenthos and different types or organic detritus (Nunes, et al., 2003).

Cultivated bivalve filter feeders play a key role in many coastal ecosystems due to their high filtration capacity and culture density. However, as more living biomass is accumulated, the proportion of primary production that is available for further growth in bivalve biomass declines, and factors such as the increase of biodeposition may contribute to significant environmental changes such as sediment anoxia (Nunes, et al., 2003).

Aquaculture is a diverse sector spanning a range of aquatic environments spread across the world, which utilizes a variety of production systems and species. It is important to recognise the problems of the impact of aquaculture such as:

- the discharge or aquaculture effluent leading to degraded water quality and organic matter rich sediment accumulation in farming areas;
- alteration or destruction of natural habitats and the related ecological consequences of conversion and changes in ecosystem functions;
- competition for the use of freshwater;
- introduction and transmission of aquatic animal diseases through poorly regulated translocations; and
- effects on wildlife through methods used to control predation of cultured fish.

Over the last years, the public pressure as well as commercial pressure or common sense has led the aquaculture sector to improve management and when it is well planned and well managed it is recognized that aquaculture has positive societal benefits (FAO, 2006).

1.1.2. Aquaculture in Portugal

The biggest natural bank of oysters in Europe was in the Tagus estuary (Pessoa, et al., 2006). The aquaculture is a traditional activity in Portugal and practised since long time ago. Oysters and other bivalves have been used as food since the earliest times. Along the Portuguese coast many shell deposits have been found composed of different bivalves (Figure 1.1), bones, ceramics and charcoal. Oyster culture began in the 1950’s, and production rose to 10,000t in 1964 (Ruano, 1997). The production consists of mollusc bottom culture, such as oysters (*Crassostrea angulata*), as well as finfish culture of sea bass, sea bream, eels, mullet, sole, and cuttle fish. Between 1990 and 1997, aquaculture grows 27% but continues to suffer a few problems. Because is still new as a large-scale industry, problems such as an incomplete legislator coverage and the inability to achieve recognition as an important sector of the economy affects this activity (Bernardino, 2000).

Figure 1.1 – Shell deposits in Tagus estuary

In Portugal, aquaculture systems and operational procedures are similar to those of the Mediterranean type (Bernardino, 2000) being the production essentially exported to France.

Vilela developed the technique of culture that was used, which involves three steps: larval attachment, spat collection and growth. According to Ruano (1997), the first step is the larval attachment, which occurs on several types of collectors, including ceramic tiles covered by a cement mixture, chains of shells, and plastic tubes that are placed on the oyster beds. Subsequently, the spat collection, where workers remove the spat that are 6 -8 months old and 2 – 4 cm long from the collectors as single oysters and place them in growout areas. The last step is the growth, where the oysters remain in the farms until they attain commercial size, at least 5 cm long. In case of water quality is poor and food is sparse, it is necessary to transfer the oysters to cleaner sites with richer water to improve quality and growth (Ruano, 1997). Cleaner sites usually have less food, given food is associated with “poorer” WQ, i.e. more chl a and more detritus. The final step (afinação) is usually in less rich waters, to clean from microrganisms, improve taste, etc.

When the Common Fisheries Policy was applied in Portugal after the mid-1980s, aquaculture began to be seen as a complement to the fishing industry and as an alternative production source of animal protein for human consumption (Bernardino, 2000).

According to National Strategic Plan for Fisheries, one of the fourth priorities to be developing since 2007 to 2013 is to strengthen, innovate and diversify the aquaculture production. The Figure 1.2 shows the evolution of oyster production in Portugal, which have increased significantly in 2001 (Direcção-Geral das Pescas e Aquicultura, 2007).

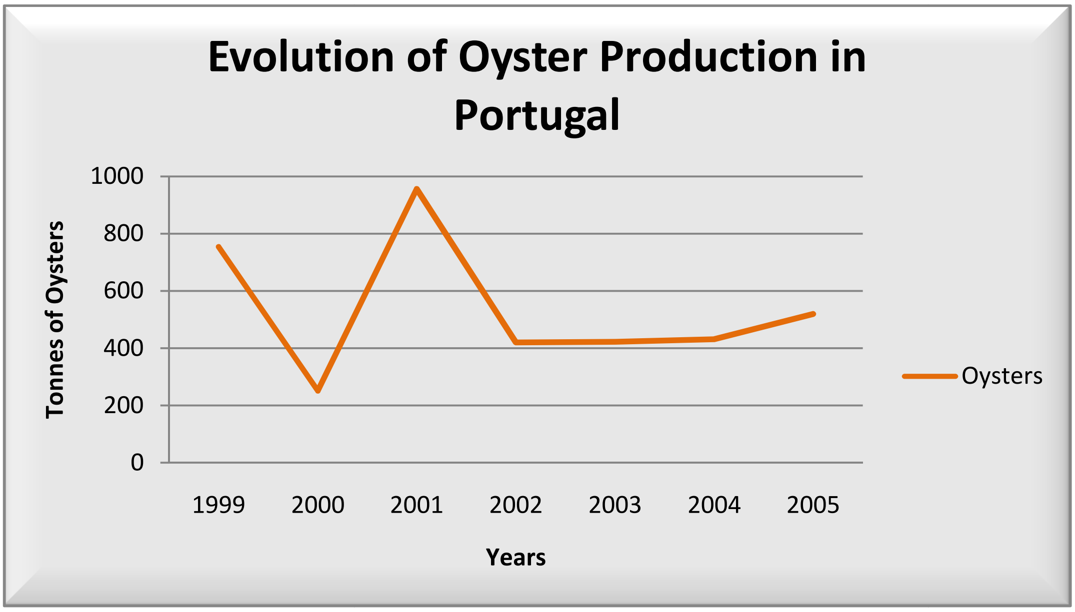

Figure 1.2 – Evolution of Oyster Production in Portugal – Font: INE/DGRA

1.1.3. Aquaculture Legislation

There are several legal frameworks related to aquaculture. Many of them are international conventions as:

- Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention);
- Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM);
- Convention on Biological Diversity (CBD);
- Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention);

Another important framework is the European Water Framework Directive (2000/60/EC) (European Comission (a), 2000) that establishes a framework for the protection of inland surface waters, transitional, coastal and groundwater, which apart from other things, prevents further deterioration, protects, and enhances the status of aquatic ecosystem. In addition, this framework requires Member States to assess the Ecological Status of water bodies, which means achieve one determinate status through the assessment of biological, hydromorphological and physic-chemical quality elements. Some works as Borja, et al. (2007) has been developed with this framework.

The Marine Strategy establishes a framework for the development of Marine Strategies designed to achieve good environmental status in the marine environment. This shall be developed and implemented n order to:

a) Protect and preserve the marine environment, prevent its deterioration or, where practicable, restore marine ecosystems in areas where they have been adversely affected;
b) Prevent and reduce inputs in the marine environment, with a view to phasing out pollution, to ensure that there are no significant impacts on or risks to marine biodiversity, marine ecosystems, human health or legitimate uses of the sea.

Marine strategies shall apply an ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the sustainable use of marine goods and services by present and future generations (European Comission (b), 2008).

1.1.4. Carrying Capacity

Carrying capacity is a fundamental concept in shellfish culture, which corresponds to the ability of the system support shellfish production.

Many authors have discussed the concept of carrying capacity. Newell (b) (2006) define “ecological carrying capacity” for bivalve aquaculture as “the standing stock of suspension-feeding bivalves where the consumption of phytoplankton, enhancement of nutrient removal, and other ecosystem services are maximized without negatively affecting water quality, sediment biogeochemistry, and overall ecosystem function”. In Nunes *et al.* (2003) the concept of ecological carrying capacity is derived from the logistic growth curve in population ecology, defined as the maximum standing stock that can be supported by an ecosystem for a given time. This concept is not only important for species cultivation but also for other concerns such as water quality and tourism (Duarte, et al., 2003).

In this work, it is adopted the definition proposed by Inglis *et al*. (2000), who divided carrying capacity into four functional categories:

i. Physical Carrying Capacity – the total area of marine farms that can be accommodated in the available physical space;
ii. Production Carrying Capacity – the stocking density of bivalves at which harvests are maximized;
iii. Ecological Carrying Capacity – the stocking or farm density which causes unacceptable ecological impacts;
iv. Social Carrying Capacity – the level of farm development that causes unacceptable social impacts.

The physical carrying capacity depends on the overlap between the physical requirements of the target species and the physical properties of the area of interest, which also include some basic chemical variables like salinity and dissolved oxygen concentration. It also depends on the culture technique. Relatively to the production carrying capacity, it might be measured in terms of wet or dry weight, energy or organic carbon (McKindsey, et al., 2006).

Carrying capacity for the culture of suspension-feeding bivalves are primarily limited by rates with that available food is renewed, which is a function of phytoplankton production and water residence time according to Dame and Prins (1998). It is also important to consider the impact of bivalve cultivation itself on water quality, sediment composition and ecosystem functioning. By recycling nitrogen, bivalves may stimulate primary productivity, according to Smaal et al. (2001). For the same reasons, in line with the concept of ecological aquaculture, bivalves may be successfully cultured alongside kelp, when nutrients excreted and egested may be absorbed by macroalgae and recycled into valuable biomass, according to Fang et al. (1996) (Duarte, et al., 2003).

1.1.5. Ecological models

According to Héral et al. (1986), global models allow the overall production of a system to be represented as an empirical function of the biomass (Raillard, et al., 1994). However, it is very restrictive to the carrying capacity.

Usually, spatially resolved ecological models simulate hydrodynamic transport in a very simple way, considering residual flows and tidally averaged situations (Duarte, et al., 2003). These are known as box models. Modelling has been used by different authors like Gerritsenet al. (1994), Raillard and Menesguen (1994), Ferreira et al. (1998), Bacher et al. (1998), Chapelle et al. (2000), Gangnery et al. (2001), Niquil et al. (2001) and Grillot et al. (1996), as an approach to examine environmental sustainability and to establish carrying capacity of shellfish aquaculture and is acknowledge as a powerful tool to support sustainable management (Nunes, et al., 2003).

Models are commonly used for determination of optimal carrying capacity, connecting physical processes, biogeochemistry and population dynamics offering a great potential for simulating the biomass of commercially important species under natural and cultured conditions (Franco, et al., 2006).

Bivalve aquaculture depends on the biological production of the coastal ecosystem, so that mathematical models are very useful for understanding and assessing the interactions in those manipulated ecosystems. The most used models are the bio-physical ones, which consider the interaction populations in the coastal marine ecosystem, as the hydrodynamic influences brought about by water circulation and mixing (Dowd, 2005). These models give estimates of growth and allow the selection of the conditions that provide a better growth potential, which are useful for aquaculture planning and management (Franco, et al., 2006).

1.2. State of art

During the period 1962-1971, Portugal exported annually over 7500 tonnes of oysters for relaying in other countries (Ramos, 1982). All cultivation in the Tagus estuary had been carried out on the intertidal areas but sometimes was commonly to be found *Crassostrea angulata* in other areas like the sub-littoral zones below low tide level (Key, 1981).

Bivalve production is good in areas that have good environments with good water quality. The capacity to produce bivalves was lost completely in the Tagus estuary because of, according to Ruano (1997), the manufacturing industries, agriculture, tourist facilities, and other activities that were introduced into it.

After the 1860's some measures were taken to improve oyster quality in the natural beds but the oyster culture only had been practiced in the middle of the 20th century.

The first law was passed in 1868 to regulate fishing in the natural oyster beds. It specified that:

1) Oysters could not be harvested from 1 April to 31 September, covering the spawning season;

2) the minimum size of oyster that could be harvested was 5 cm, and;

3) oysters in intertidal zones could be gathered only by hand.

Subsequently, several measures were passed covering special situations to protect human health. In 1895 the first "Regulation law for the oyster industry, oyster parks, and oyster culture" appeared. In 1923 the first "Sanitary regulation law of oyster industry" was passed. In 1953, the government built the first depuration plant for oysters in the Tagus estuary and in 1972 it was published the new "Regulation law for the oyster industry" (Ruano, 1997).

The Portuguese oyster has increased in almost all brackish water estuaries, lagoons and rias. It can occupy areas from intertidal and subtidal zones to the deepest parts of canals and from river mouths to several kilometres upstream. It can occur on substrates of sand, sandy mud, silt, and shells (Ruano, 1997).

The Oysters Mortality

Since 1973, the Portuguese oyster experienced an unexpected and extensive mortality that leads to the ending of production in the Tagus estuary and around 1974 it had occurred in France and England on such a scale that the trade was no longer economic.

According to Vilela (1975), pollution was the main reason for decline of the oyster industry, particularly in the most productive areas. One of the causes was attributed to the introduction and uses of an anti-fouling agent the tri(n-butyl)tin (TBT) by shipyards, which levels of TBT were relatively high in the open Tagus estuary and in docks (Bettencourt, et al., 1999).

Other factor that made the production of oysters declined was the occurrence of several epizootics, namely the “oyster gill disease”, which according to Comps et al. (1976) is caused by an iridovirus. This disease reduced the filtering capacity and killed some young and stressed animals. Associated to this problem was the phenomenon of abnormal shell growth. The reduction in growth of shell edges and thickening of the two surfaces of the shell with multiple layers, resulted in very heavy shell weight in relation to the overall size of the shell and of the oyster contained within it (Key, 1981).

In addition to those factors the “foot disease”; several protozoan diseases; an ineffective or absent management strategy to protect the natural beds; overharvesting and depletion of the beds by fishermen and non-existence of hatcheries; which could had provided farmers with juvenile oysters when natural spatfalls were declining, increase the mortality of the oysters (Ruano, 1997).

The marine pollution has been increasing during the last years and represents a potential risk to the aquaculture industry as seafood might be in poor condition for human consumption (Bayen, et al., 2007).

Estuaries

According to the definition of Pritchard (1967), an estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted with fresh water derived from land drainage (Lazier, 2006). Perillo (1995) develops another further definition as, an estuary is a semi-enclosed coastal body of water that extends to the effective limit of tidal influence, within which sea water entering from one or more free connections with the open sea, or any other saline costal body water, is significantly diluted with fresh water derived from land drainage, and can sustain euryhalines biological species for either part or the whole of their life cycle (Dyer, 1997).

Estuaries are intensively used for aquaculture in many countries, and suspension-feeding bivalves are among the most cultivated organisms in these ecosystems. This is a “passive” type of culture, where the animals feed on natural suspended matter and their metabolites being dispersed by currents and waves (Duarte, et al., 2003).

Estuaries are also economically important features of the ocean because of their high biological productivity, their proximity to large cities with their wastes, and their increasing use as sites for aquaculture (Lazier, 2006).

The Tagus estuary is highly productive ecosystem, and has considerable conservation value, since it provides an optimum habitat for many crustacean, mollusc, fish and bird species. This has led to the creation of a Natural Reserve in 1976, covering a large surface of estuarine water, mud banks, salt pans, salt marshes, islands and agricultural land. However, some of its natural resources have been degraded in the last 30 years due to the increased water and soil pollution. An example of this fact is the extinction of the oyster banks, *Crassostrea angulata*, partly caused by TBT. In the past, oysters were the most important commercial resource of the estuary (Ferreira, et al., 2004). Compared with the open sea, the estuary has many advantages in the primary production of organic matter and the environmental conditions (Ryther, 1969).

Mesotidal estuaries, like Tagus estuary, are favourable areas for shellfish culture. For being protect from the turbulence of the sea, this type of estuaries offer good trophic conditions due to strong tidal currents which ensure an intensive renewal of food within the area (Raillard, et al., 1994).

Estuaries can be distinguished by the instability of environmental conditions, variations in great amplitudes of different parameters such as tides, temperature, salinity, dissolved oxygen, organic substances, nutritive salts, turbidity and also by the multiplication of the various allowing important energetic transfers. The *Crassostrea* are especially well adapted to those fluctuant conditions and their nutritional requirements well covered in estuarine environment (Lubet, et al.).

Crassostrea angulata

In this is study it is used the Portuguese oyster, Crassostrea angulata (Figure 1.3), which is from the family of oysters Ostreidae. Many authors as Esperança (1981/1982) and Vilela (1975) had written about their taxonomy, which for this work is not given much importance.

Figure 1.3 – Image of Crassostrea angulata

Bivalves are poecilosmotics, which means that the concentration of the body fluid being the same than these of external seawater (Lubet, et al.). Therefore, the environmental conditions are very important to the oysters' growth.

As well as the other suspension-feeding bivalves, oysters play an important role in the aquatic systems. Their biodeposits, like filter suspended particles and the undigested remains, could be extremely important in regulating water column processes (Newell (a), 2004).

Crassostrea angulata is euryhalines but salinity influence respiration, nutrition, gametogenesis, growth, larvae survival and the effects are different according to the age or some environmental factors (e.g. temperature, dissolved oxygen) (Lubet, et al.). It tolerates a wide salinity range, even as low as 2-6‰ in winter and after heavy rains. It is shown that after 1-2 months of rains, a large number of oysters in the upper parts of estuaries become affected by so-called "fresh water edema" due to osmo-regulatory dysfunction. In contrast, during summer, in beds close to river mouths or inside lagoons, salinities can rise to 35-38‰ without any apparent stressing of the oyster (Ruano, 1997).

The growth of *Crassostrea angulata* is null under 10ºC and can survive in an aerobiosis during 10 days at 14^0 – 15^0C and more at low temperatures. Filtration stops at 8^0C (Lubet, et al.). The temperature range in its habitat varies from a minimum of 8^0-10^0C in northern waters during winter to 20^0-30^0C in southern lagoons during summer (Ruano, 1997).

Oysters are filter feeders, animals feeding on planktonic algae, organic particles and also bacterias, which are in good conditions for nutrition and growth in estuarine environment (Lubet, et al.).

During the rainy season, the water in large estuaries carries a large quantity of silt. It flocculates and settles on oyster beds, causing mud blisters in the shells of oysters as well as heavy mortalities of oyster spat (Ruano, 1997).

The main oyster predators are several species of crabs (especially the green crab, *Carcinus maenas*), gastropods, sea stars, and sea birds. Generally, oyster larvae are eaten by jellyfish (Ruano, 1997).

Although are genetic and phenotypic differences between *Crassostrea angulata* and Pacific oyster, *Crassostrea gigas*, they are taxonomically close (Batista, et al., 2007). For this reason, we used the *Crassostrea gigas* object in the ecological model.

1.3. Objectives

The objective of this work is to develop and implement an ecological model, which simulates the aquaculture of oysters – *Crassostrea angulata* – in Tagus estuary.

Firstly, it is necessary to define the localization of the old oysters-bed in the study area and pass to GIS. Following that, it is needed to process data from the database which will be use to calibrate and validate the model. After the model validation, it was elaborated two different scenarios for testing the model.

2. Methodology

2.1. Study area

The study was carried out in the Tagus estuary, in Portugal (Figure 2.1), one of the largest estuaries in Europe, covering an area of 320 km^2. The main freshwater source to the estuary is the Tagus River, having an annual average flow of 400 m^3 s^{-1} (Alvera-Azcárate, et al., 2003). This discharge vary significantly from winter to summer so the residence time of freshwater in estuary is highly variable, ranging from approximately 6 to 65 days (Brogueira, et al., 2006). About 112 km^2 are intertidal areas, which 19 km^2 are occupied by salt marsh vegetation and 81 km^2 by mudflats. The average depth is 10 m (Ferreira, et al., 2004).

The Tagus estuary is mesotidal and its circulation is mainly tidally driven, with mean tidal amplitude of 2.6 m, ranging from 4.1 m in spring tides to 1.3 m in neap tides. Tides are semi-diurnal ranging between 3.56 m at high tide and 0.87 m at low tide (Ferreira, et al., 2004).

The combined factors of low average depth, strong tidal currents and low input of river water make this a well-mixed estuary, with stratification being rare and occurring in specific situations such as neap tides or after heavy rains (Ferreira, et al., 2004).

Figure 2.1 – Localization of Tagus estuary in Portugal map

2.2. Localization of the aquaculture areas and definition in GIS

The areas where was made the study of the aquaculture viability were the oldest oysters' bed in the Tagus estuary (Saldanha, 1980). In Figure 2.2, it is possible seen them in zones less deep.

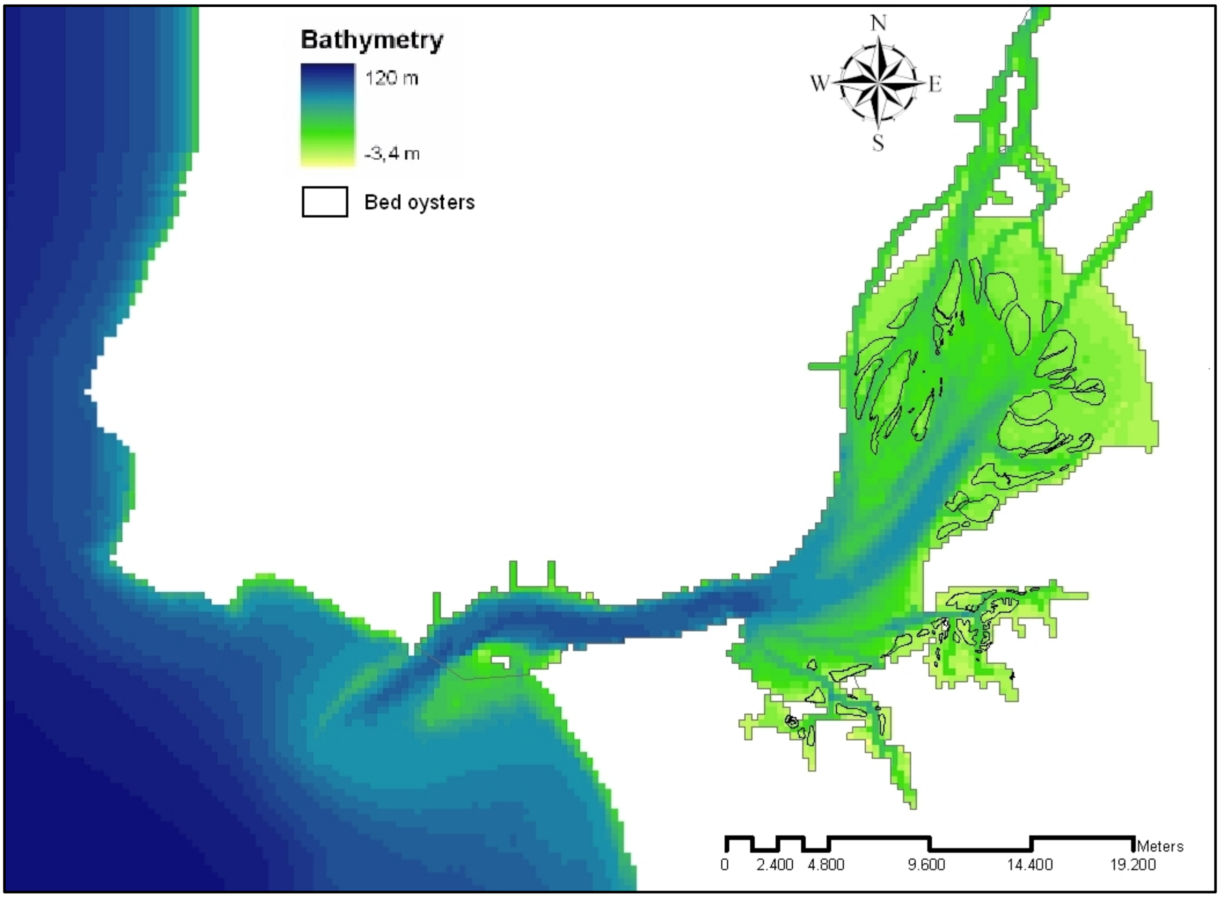

Figure 2.2 – Localization of the bed of oysters in Tagus estuary

2.3. Loading and treatment of data

To use the ecological model it is needed several information that it must be previous treated. According to that, it was used some tools which are identified and shown their relationship with the model in the figure below (Figure 2.3). During the work, it will be explain more about each one of these tools.

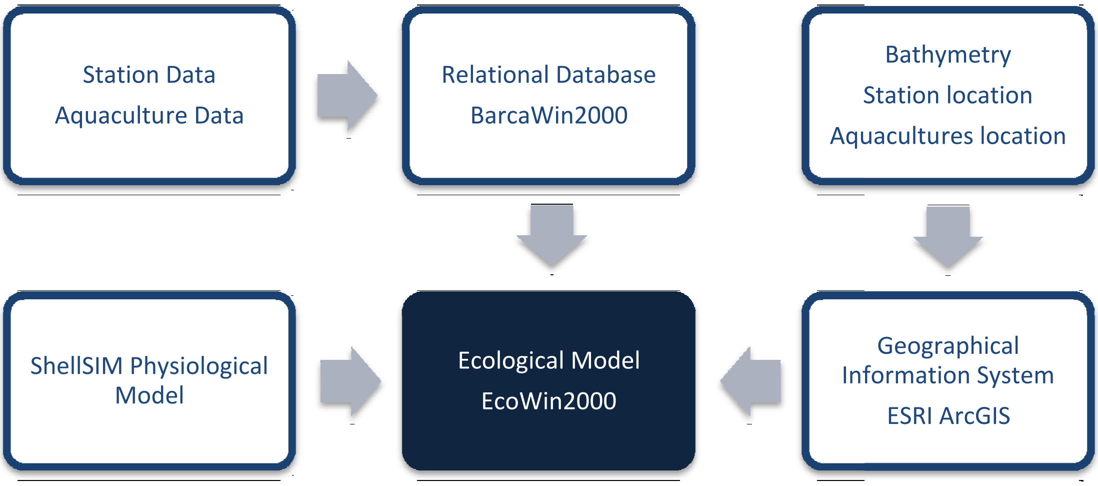

Figure 2.3 – Relationship between tools used in this study.

One of the tools, which have already been used in aquaculture areas location, is the Geographical Information System (GIS). This will be used again in others operations which are shown in Table 2.1. The coordinate system used for all data was UTM Zone 29N which uses the WGS-1984 Datum and the Transverse Mercator Projection. The software used for all GIS operations was ESRI ArcGIS 9.2.

Table 2.1 – Geographical information used in the present study.

Layer Type	Spatial Resolution (in meters)	Layer type	Data type
Bathymetry	30	Raster (Regular grid)	Real
Sampling station data	-	Vectorial (Points)	Integer
Box definition	-	Vectorial (Polygons)	Integer
Aquaculture areas	-	Vectorial (Polygons)	Integer
Coastline	-	Vectorial (Line)	Integer
Shellfish sampling stations	-	Vectorial (Points)	Integer

2.3.1. Water quality

A wide range of water quality data are available from a survey carried out during 1980-1983 on the Tagus estuary with 25 measuring stations. Typically, 30 water quality parameters were measured at various tidal situations and normally at three different depths (Ferreira, et al., 2004). The existing data were loaded into the relational database BarcaWin200^{TM} and used in this work.

This database, which is written in Turbo Pascal for Windows and C++, and uses the Borland Paradox Engine for all database-related functions, includes a program for file conversion between different formats, the data files and database software for analysis and exploration of the data (Ferreira, et al., 1998).

The sampling stations used in this work are shown in Figure 2.4.

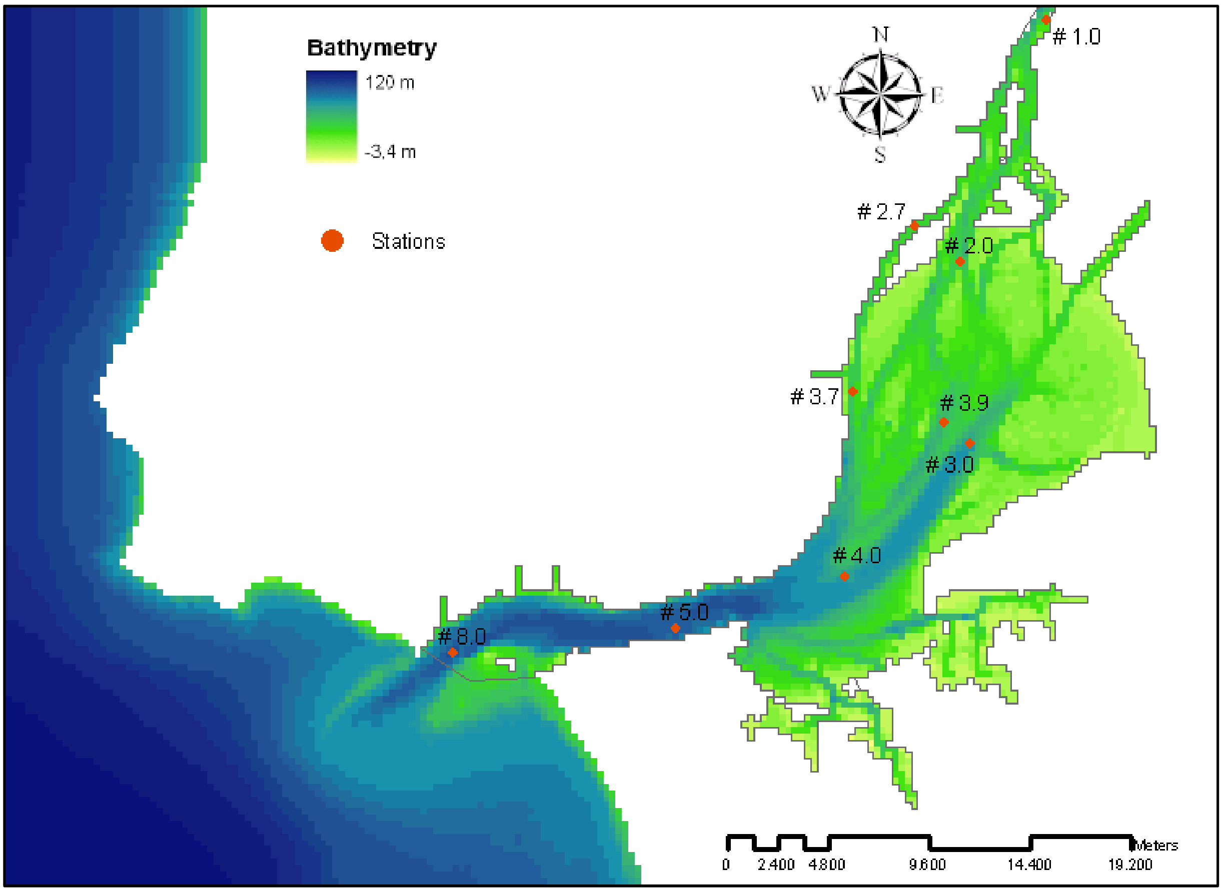

Figure 2.4 – Tagus estuary with stations

2.3.2. Grow and techniques of culture

In the present work, it was adopted the technique of culture used in Thau Lagoon (France), where the oysters are fixed on ropes, which are suspended in the water column from culture tables (Figure 2.5). Some works were realised there with the purpose to improve the modelling oyster population, as Gangnery (b) et al. (2003).

Next illustration (Figure 2.5) was extracted from Gangnery (a) et al. (2003), and it is a sketch of a typical oyster table. This type of culture consists in tables that are made of railway bars pushed in the sediment, where is supported horizontal iron bars from which the ropes are suspended in the water column. The ropes length varies depending on water deeph.

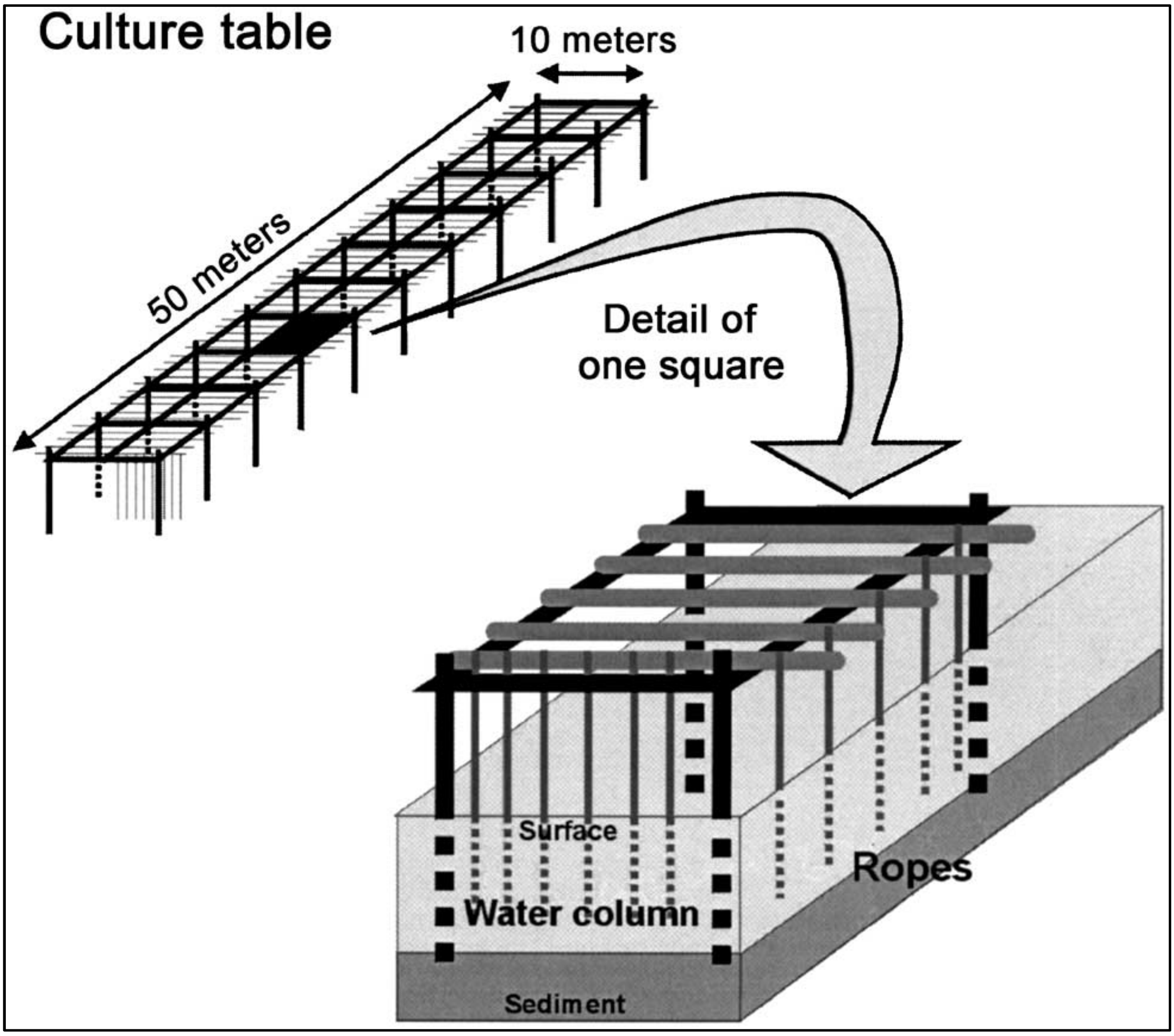

Figure 2.5 – Sketch of typical oyster table

For each box, it was calculated through GIS the licensed areas of oysters. Those are shown in Table 2.2.

Table 2.2 – Licensed area for oysters

Box	4	5	6	7	8	9	10	11
Licensed Area for Oysters (ha)	19,37	211,90	245,20	1164,35	1478,35	363,46	221,42	230,28

2.4. Application of ecological model

The ecosystem was assumed to be vertically homogeneous, such as Ferreira, et al. (1998), and divided into compartments. The estuary was divided into 13 ecological boxes, which could be seen in Figure 2.6, and it was used an upwind 1-D transport scheme to calculate the transport of particulate and dissolved substances between boxes.

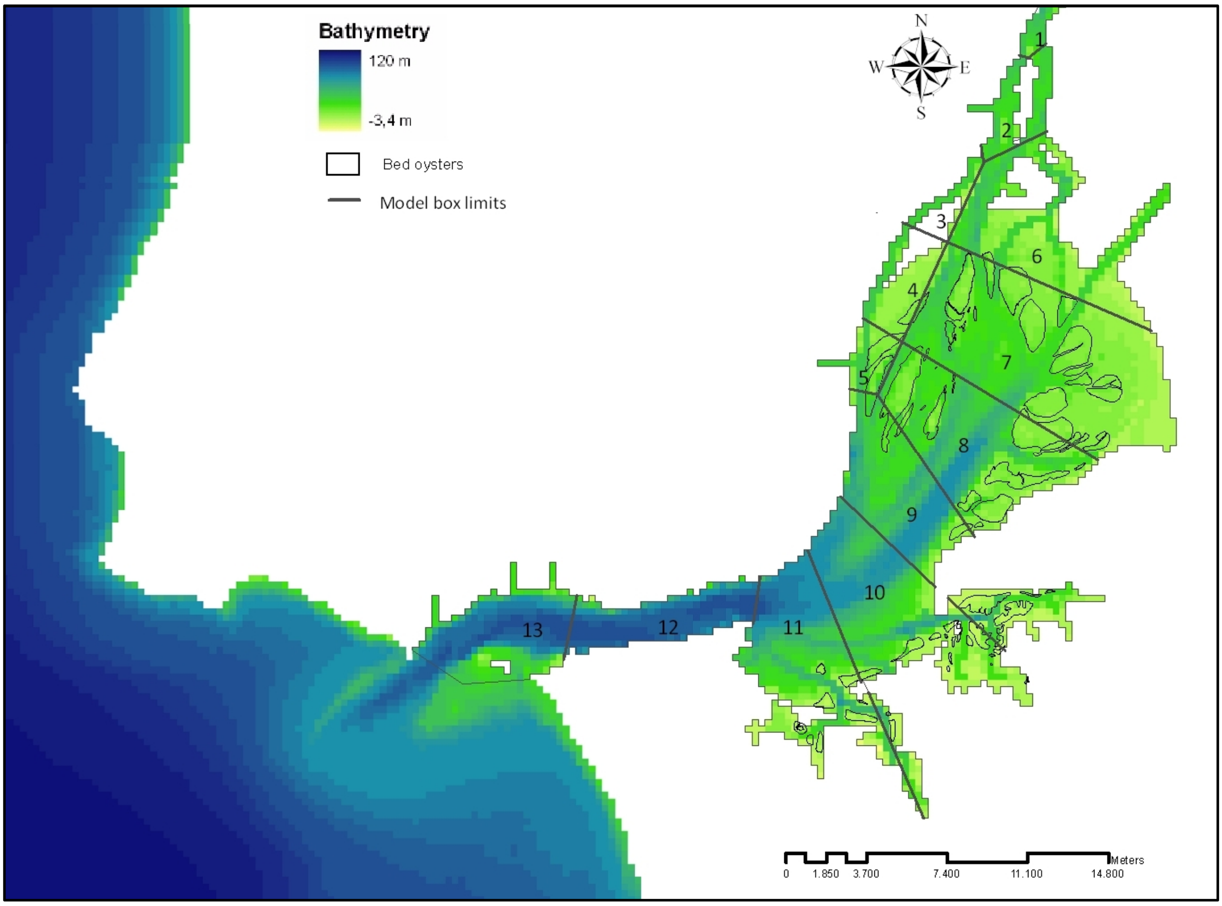

Figure 2.6 – Tagus estuary with model box division

The model was implemented using EcoWin2000 developed by Ferreira (1995). This software uses object-oriented programming (OOP) that consists in two essential modules: a shell module that interacts with the various objects and "ecological" objects. Both have been programmed in C++ for Windows^{TM} (Ferreira, 1995). The objects used in this study are shown below in Table 2.3.

Table 2.3 – EcoWin objects implemented for Tagus estuary

Object type	Object name	Object outputs
Forcing functions	Flow	Main flow
	Light	Total and photosynthetically active radiation (PAR) surface irradiance
	Air temperature	Air temperature
	Tide object	Tidal height
	Water temperature	Water temperature
State variables	Hydrodynamics 1D	Salinity
	Nutrients	Ammonia, nitrite, nitrate, phosphate silica and dissolved inorganic nitrogen (DIN)
	Suspended matter	Suspended matter, particulate organic matter (POM) and particulate organic carbon (POC)
	Phytoplankton	Phytoplankton biomass
	Zoobenthos	Oyster density, biomass, single individual weight and length, phytoplankton uptake and licensed area for oysters
	Man	Oyster total seed and harvest

For this study, the full EcoWin2000 model runs with eleven different objects, containing 23 forcing functions and 59 state variables. These simulate the relevant biogeochemistry and provide the appropriate drivers for the ShellSIM individual growth formulations (Ferreira, et al., 2008).

These drivers, known as “forcing functions”, with potential to affect physiological responses simulated by ShellSIM include food availability, food composition, seawater temperature, salinity and aerial exposure. Data required by ShellSIM to compute food availability and composition include measures of the suspended availabilities of total particulate matter (TPM; mg/l), particulate organic matter (POM; mg/l) and Chlorophyll a (CHL; μg/l) (Hawkins, 2008).

ShellSIM has been developed by Dr A. J. S. (Tony) Hawkins of Plymouth Marine Laboratory as a cost-effective tool for use by farmers, regulators, teachers and scientists, and which meets the above challenges by successfully simulating dynamic adjustments in feeding, metabolism and/or growth across broad natural ranges of environmental variability in 8 shellfish species to date (Hawkins, 2008). This software is a simple hands-on tool, calibrated to predict physiological responses of suspension-feeding shellfish exposed to full natural environmental variations, based upon principles of net energy balance (Figure 2.7).

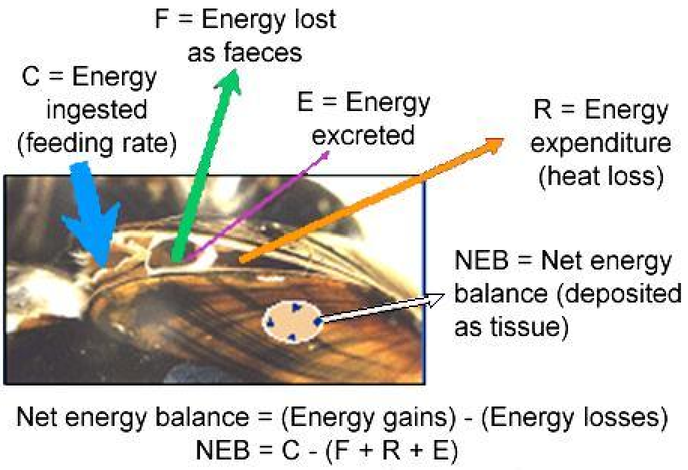

Figure 2.7 - Physiological components of net energy balance

The population dynamics was simulated trough a class transitional model (Simas, et al., 2007), which simulates the transition of the shoots between weight classes in order to describe plant population density per unit area. The equation (1) expresses the class transition:

$$\frac{\partial n(s,t)}{\partial t} = \frac{\partial [n(s,t)g(s,t)]}{\partial s} - \mu[(s)n(s,t)] \qquad (1)$$

Where,

- t, time;
- s, weight class;
- n, number of shoots;
- g, scope for growth (growth rate);
- μ, mortality rate.

The parameters used are shown in table below (Table 2.4).

Table 2.4 – Values of the parameters

Object	Parameter	Value
Water Temperature	Minimum temperature	9,9 ºC
	Maximum temperature	24 ºC
	Phase	150
Light	Cloud Cover	0,5
	Cloud Amplitude	0,3
	Cloud Peak	350
	Cloud Phase	180
Suspended Matter	Turbulence	0,5 (calibrated value)
	Latitude	39 ºC
	Salinity	15 psu
	Temperature	15 ºC
	POC fraction	0,043
Phytoplankton	ThresholdNH_4	1µmol L^{-1}
	kNH_4	2 µmol L^{-1}
	Pmax	0,2 h^{-1} (calibrated value)
	Ks	4 µmol L^{-1} (calibrated value)
	Iopt	450 (calibrated value)
	Death loss	0,8 (calibrated value)
	q10PH	0,05
	RTMPH	5
Zoobenthos	Number of oyster classes	10
	Oyster class amplitude	10 g TFW ind.
	Oyster mortality	5,48 x 10^{-4} d^{-1}
Man	Oyster first seeding day	120 d
	Oyster first harvest day	285 d

2.4.1. Calibration

Model calibration is a critical phase in the modelling process and is done by comparing model results with measurements and adjusting the structure and parameters of the model such that the model results and observations match adequately (Janssen, et al., 1995). For this comparison, were used qualitative techniques based on visual inspection of the results, as well as quantitative techniques that express the agreement between model and data numerically. The performance measures used in this model calibration were the Average error (AE), Relative mean bias (rB) and Correlation Coefficient (r), which formulas are expressed below, Table 2.5:

Table 2.5 – Performance measures for comparing model results and field data.

Symbol	Formulation
AE	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{n} = \bar{P} - \bar{O}$
Rb	$\frac{(\bar{P} - \bar{O})}{S_o^2}$
R	$r = \frac{\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2} \cdot \sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}}$

Where,

- P_i and O_i are the model value and field data value;
- $\bar{P}$ and $\bar{O}$, are their means and;
- S_o^2 the variance of field data value.

After crossing the GIS information with the location of the stations and ecological model boxes, it was started the calibration (Figure 2.8).

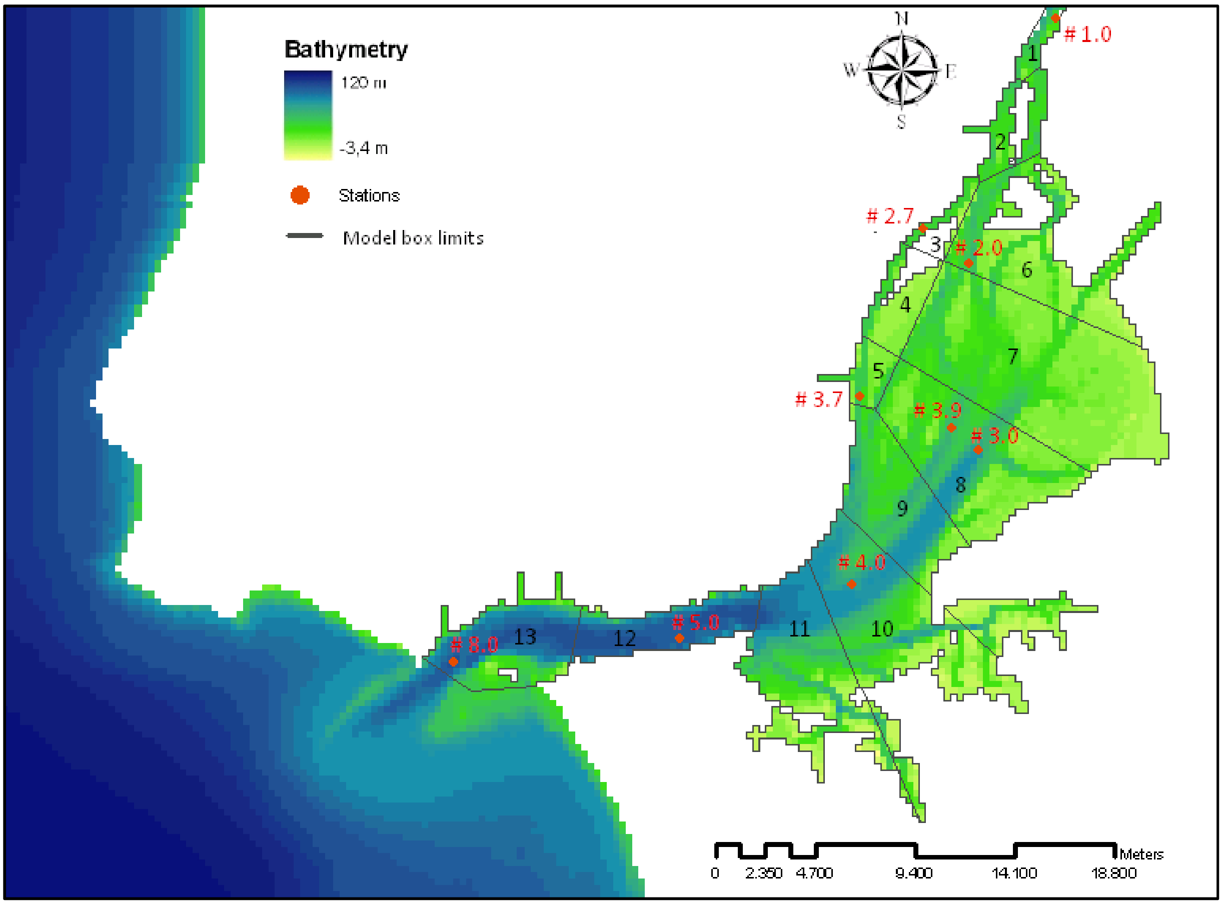

Figure 2.8 – Tagus estuary with model box limits and stations

2.4.1.1. Forcing Functions

Water Temperature

Measured water temperature from Database 1980 was used for the calibration of the water temperature. Data from stations #1.0, #2.0, #2.7, #3.7, #3.9, #4.0, #5.0 and #8.0 were selected which represent boxes 1, 3, 5, 6 , 8, 10, 12 and 13 that are illustrated in Figure 2.8

Light

There was no data of the light available.

River Flow

The river flow was calibrated with average month data from the Omnias Station (18E/04H) Database 1980 that represents the Box 1. This database can be accessed on National Information System Of Water Resources (SNIRH, 1995 - 2008).

2.4.1.2. State Variables

Salinity

For salinity calibration was used the Database 1980. This measured data are from stations #2.0, #2.7, #3.7, #3.9, #4.0, #5.0 and #8.0, as they are representative of the different boxes that are already referred.

Suspended Particulate Matter

The suspended particulate matter (SPM) was calibrated with the data field from the Database 1980, where stations #1.0, #2.0, #2.7, #3.7, #3.9, #4.0, #5.0 and #8.0 were selected.

Phytoplankton

Relatively to the phytoplankton biomass calibration it was used the data of chlorophyll *a* concentrations from Database 1980. The stations selected for that were #1.0, #2.0, #2.7, #3.7, #3.9, #4.0 and #5.0.

Zoobenthos

As no data of zoobenthos biomass are available in the BarcaWin Database 1980, so that it was used data from Esperança (1981/1982) (Annex A) to calibrate Zoobenthos.

2.4.2. Validation

For the validation process it was used qualitative techniques and quantitative techniques, as are already mentioned above in calibration. Because it was fewer data, some stations would not be considered.

2.4.2.1. Forcing Functions

The only forcing function validated in this work was water temperature with data from Database 1982. For that, the stations selected were #1.0, #2.0, #3.9, #4.0 and #5.0, which represented boxes 1, 6, 8, 10 and 12 of the ecological model.

2.4.2.2. State Variables

Salinity

The salinity validation it was made with data from Database 1982, which stations #2.0, #3.9, #4.0 and #5.0 were used.

SPM

SPM was also validated with Database 1982. For it were used stations #1.0, #2.0, #3.9, #4.0 and #5.0.

Phytoplankton

Like SPM for phytoplankton biomass validation it was used the same stations from the Database 1982.

Zoobenthos

The zoobenthos were validated with data from Ramos (1982) (Annex B), which stations are shown in Figure 2.9.

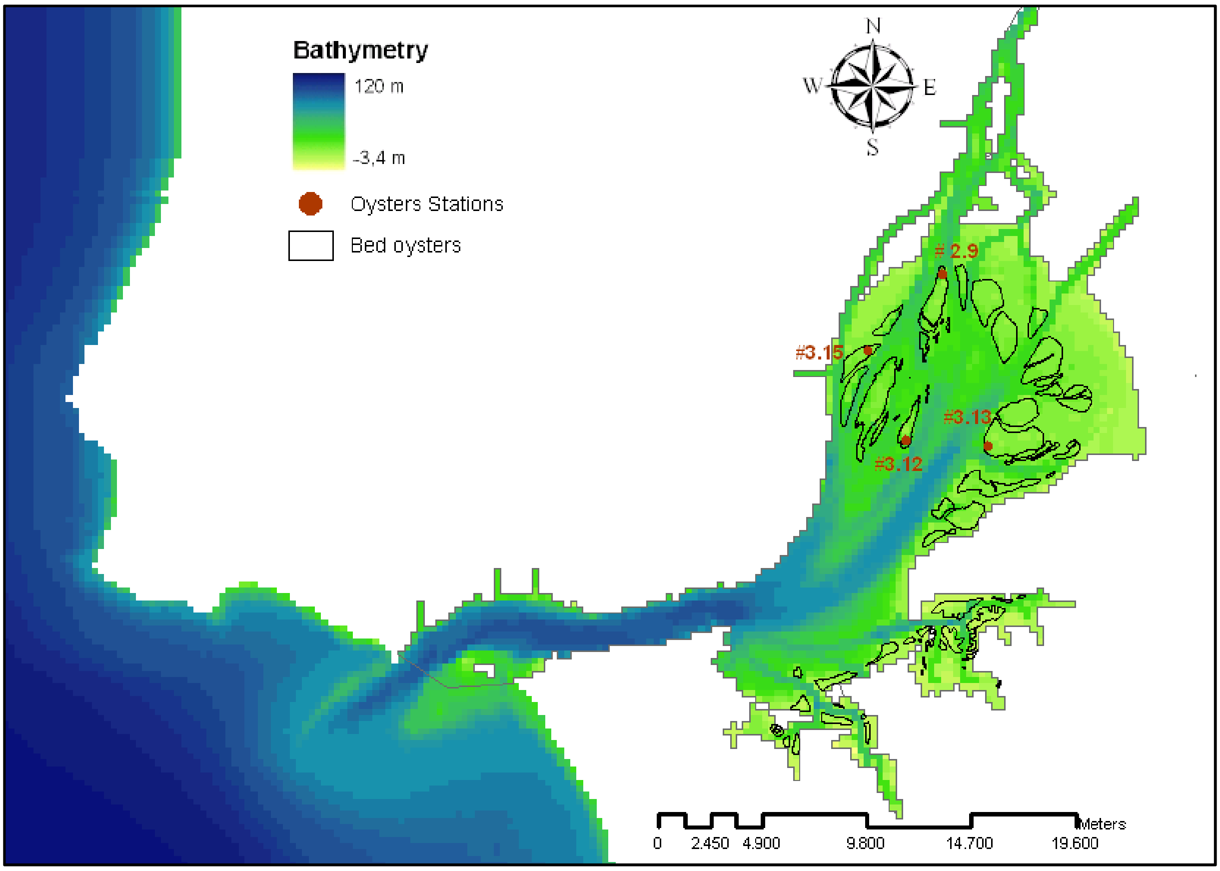

Figure 2.9 – Tagus estuary with the oysters' stations

2.5. Scenarios

Scenario I

Global climate change is very likely to give rise to large-scale impacts on the physical and geochemical characteristics of the oceans and coast including, in addition to others, increases in sea surface temperature and sea level (European Environmental Agency, 2007). Because of that, it is chosen for Scenario I the increase of 3^{0}C on water temperature.

Scenario II

In intention to maximize the oysters' production and obtain the better conditions to their growth, it was changed the first seeding day from starting in 120 day to 90 day, which means, start to seed in April instead of May.

3. Results and discussion

3.1. Calibration

The calibration was made on the third year run of model, where the model was already stabled and the results presented below were obtained at the end of the calibration of the 13 box model of the Tagus estuary.

3.1.1. Flow

Although correlation between model results and field data do not present a good result, the average error is not very high, which it is possible seen in Table 3.1.

Table 3.1 – Statistics Results – Flow Calibration

	Box 1
Relative Bias	-0,1
Average Error (%)	36%
Correlation	-0,15

The Figure 3.1 illustrates the evolution of model along the year. In spring, the flow decreases as expected, and in beginning of autumn start to increase again. Therefore, the model result is considered significantly good.

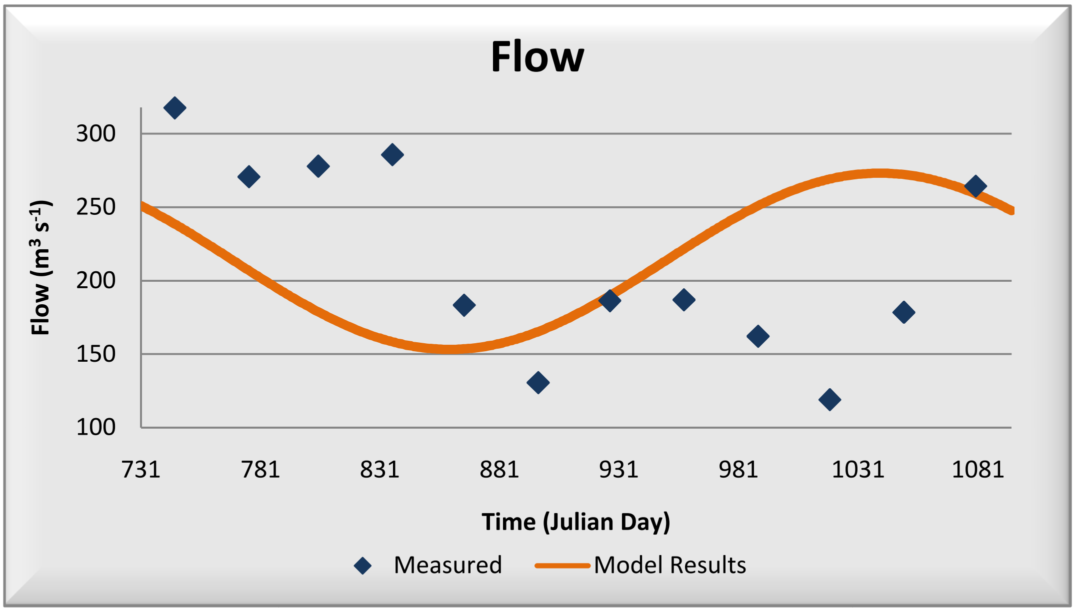

Figure 3.1 – Flow: Model Calibration

3.1.2. Water Temperature

After calibration, water temperature presents a very good correlation between model results and field data as it can be seen in Table 3.2. The majority of the boxes used in this calibration have a correlation coefficient higher than 0,90 as also a minor average error and relative bias, which means the model represents very well water temperature.

Table 3.2 – Statistics Results – Water Temperature Calibration

	Box 1	Box 3	Box 5	Box 6	Box 8	Box 10	Box 12	Box 13	Global
Relative Bias	0,5	-0,4	-1,6	-0,3	-1,1	-1,4	-2,3	-2,7	-1,1
Average Error (%)	7%	12%	18%	12%	13%	20%	21%	27%	15%
Correlation	0,96	0,96	0,91	0,90	0,92	0,81	0,79	0,16	0,77

The model results and measured data are presented below in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.7, Figure 3.8 and Figure 3.9.

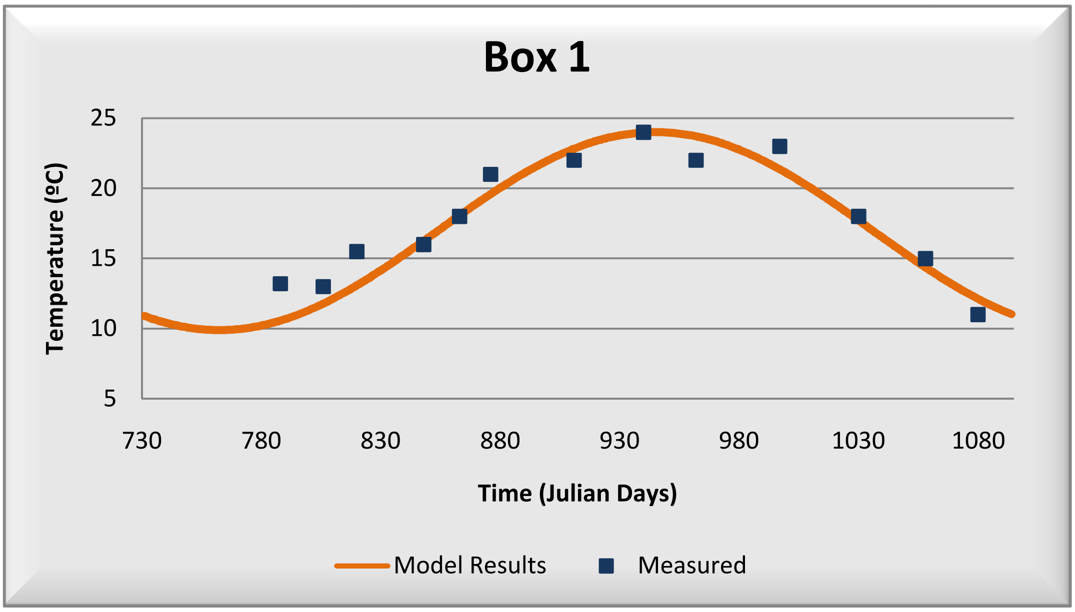

Figure 3.2 – Water Temperature: Model Calibration – Box 1

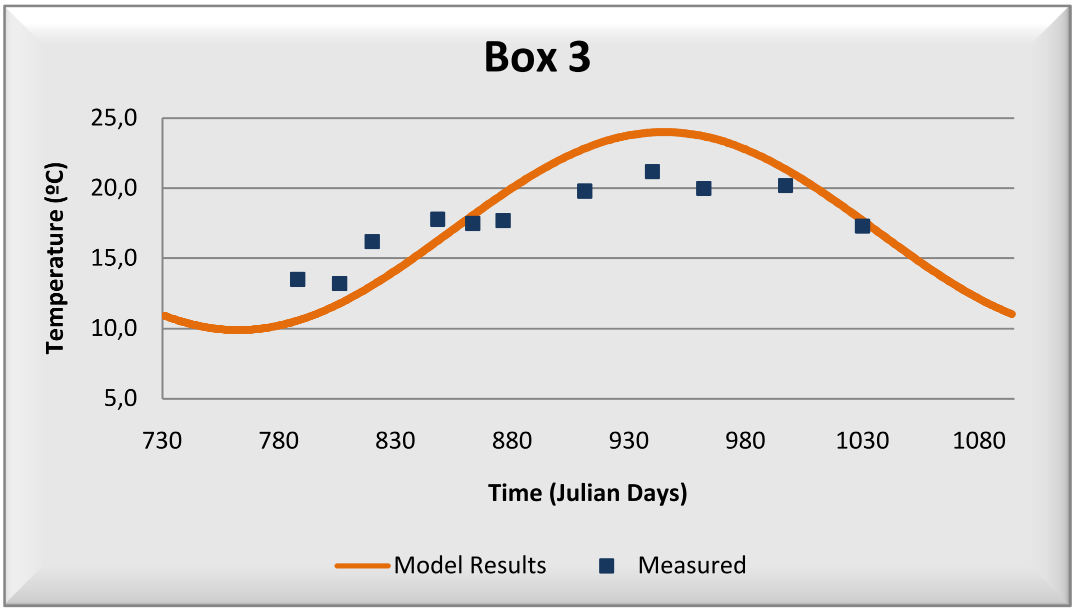

Figure 3.3 – Water Temperature: Model Calibration – Box 3

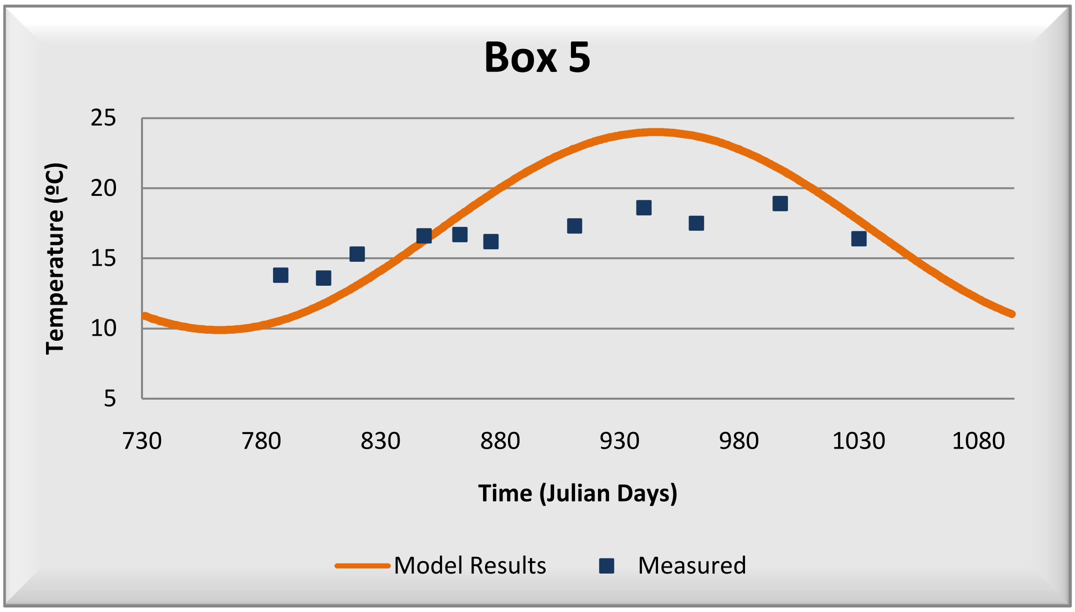

Figure 3.4 – Water Temperature: Model Calibration – Box 5

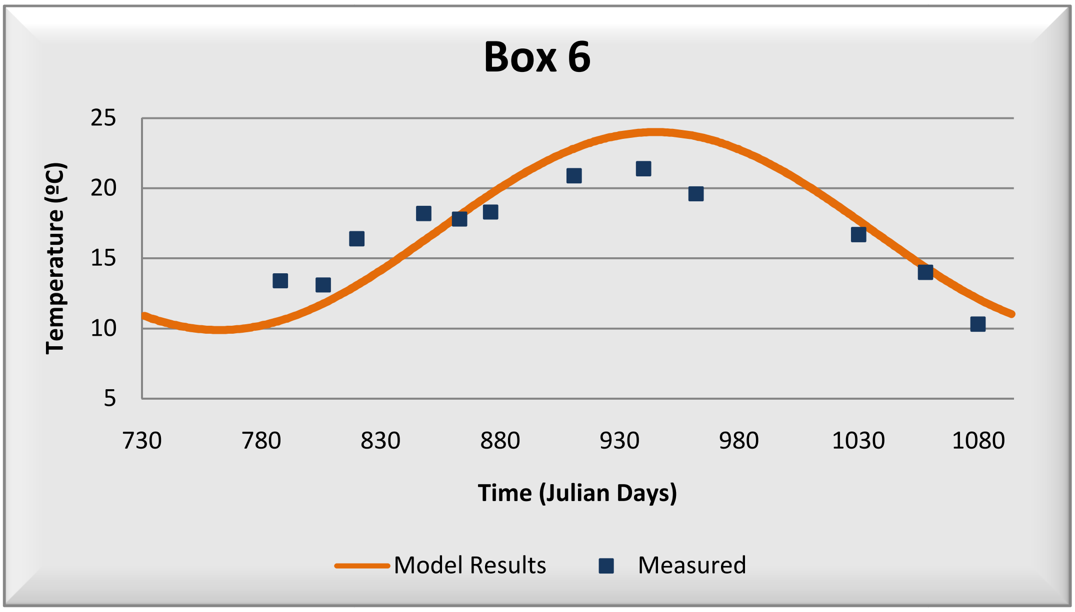

Figure 3.5 – Water Temperature: Model Calibration – Box 6

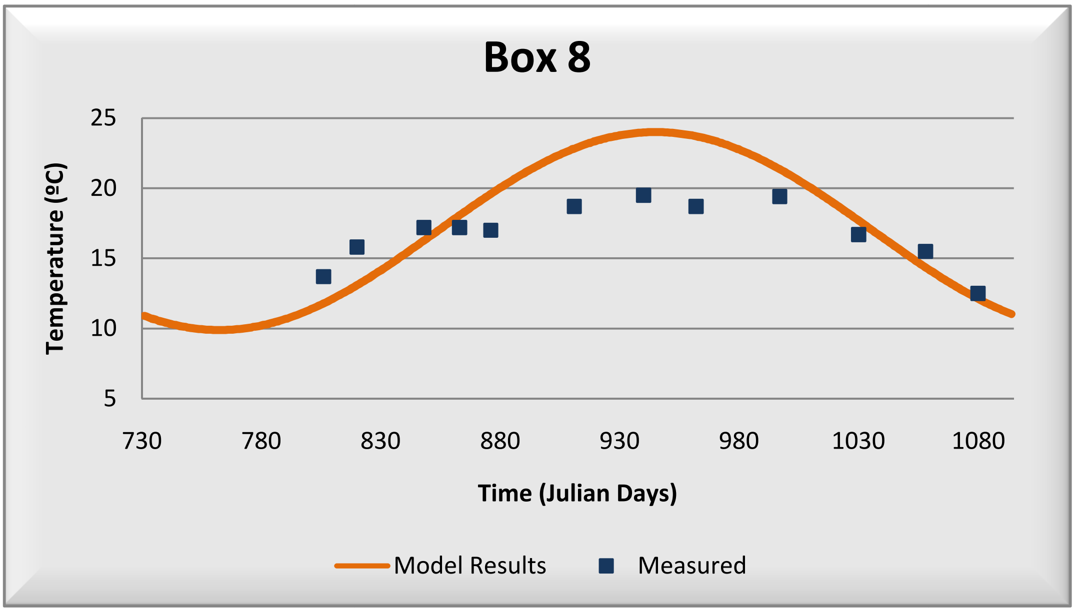

Figure 3.6 – Water Temperature: Model Calibration – Box 8

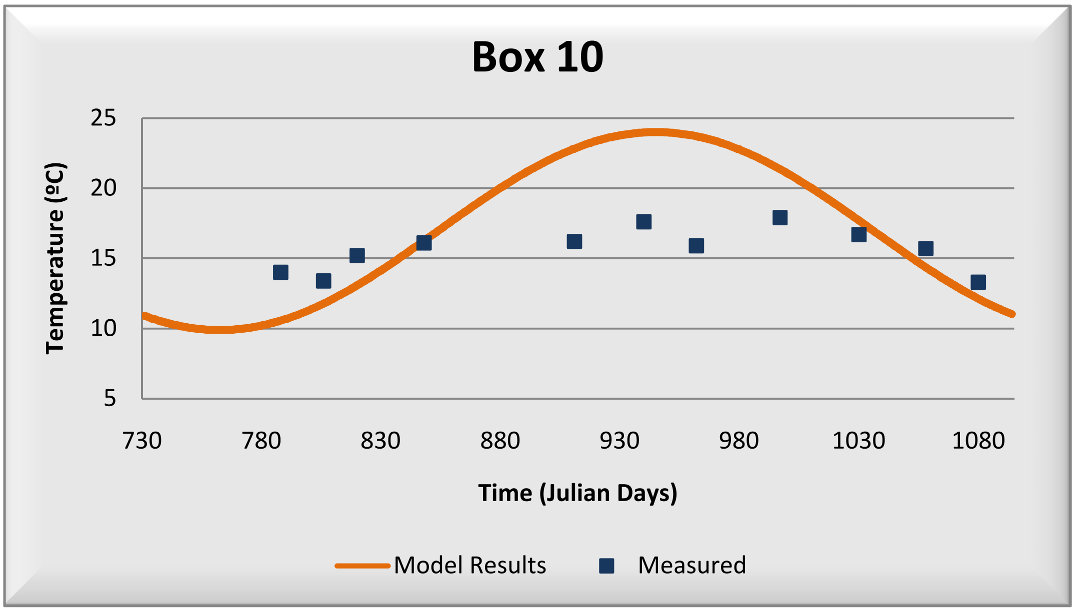

Figure 3.7 – Water Temperature: Model Calibration – Box 10

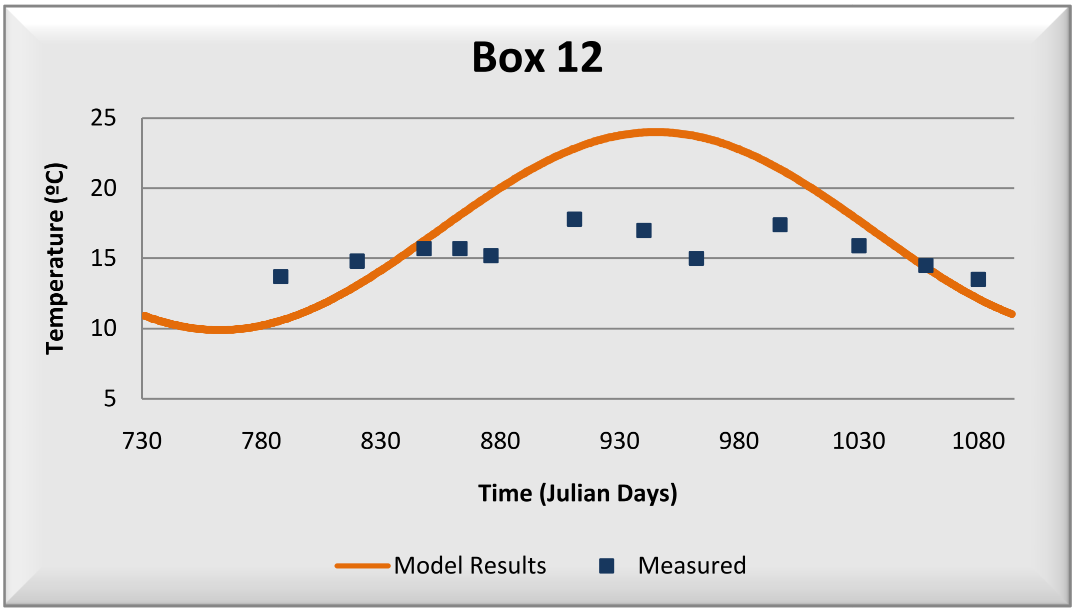

Figure 3.8 – Water Temperature: Model Calibration – Box 12

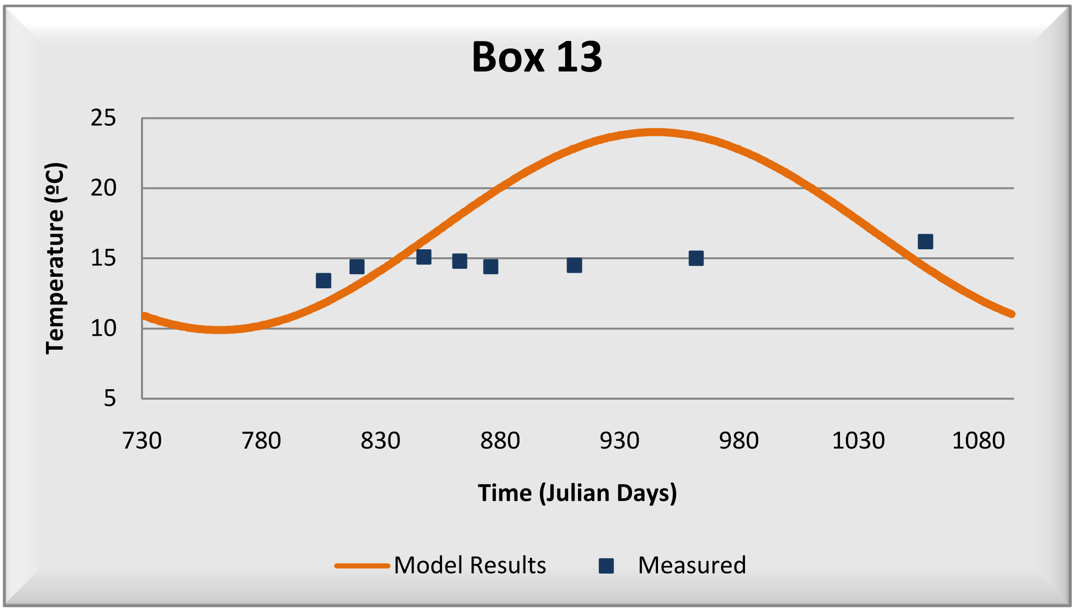

Figure 3.9 – Water Temperature: Model Calibration – Box 13

3.1.3. Salinity

Salinity is run in the model by variation of the river flow, which means low flow in summer, higher salinity and the opposite happens in winter. Despite the individual box correlation coefficient isn't very good, as it is shown in Table 3.3, the global variation presents a good one correlation, with r=0,75. Besides the bad individual correlation coefficient, the average error and relative bias have lower values, which at the end represent the satisfying relation between the model and the measured data.

Table 3.3 – Statistics Results – Salinity Calibration

	Box 3	Box 5	Box 6	Box 8	Box 10	Box 12	Box 13	Global
Relative Bias	1,9	-2,1	1,8	-2,3	-0,7	-0,6	1,1	-0,1
Average Error (%)	41%	13%	37%	11%	10%	7%	4%	18%
Correlation	0,38	0,15	0,21	0,21	0,10	0,47	0,36	0,75

The figures below, Figure 3.10, Figure 3.11, Figure 3.12, Figure 3.13, Figure 3.14, Figure 3.15 and Figure 3.16, show the model results and the measured data for boxes 3, 5, 6, 8, 10, 12 and 13 respectively.

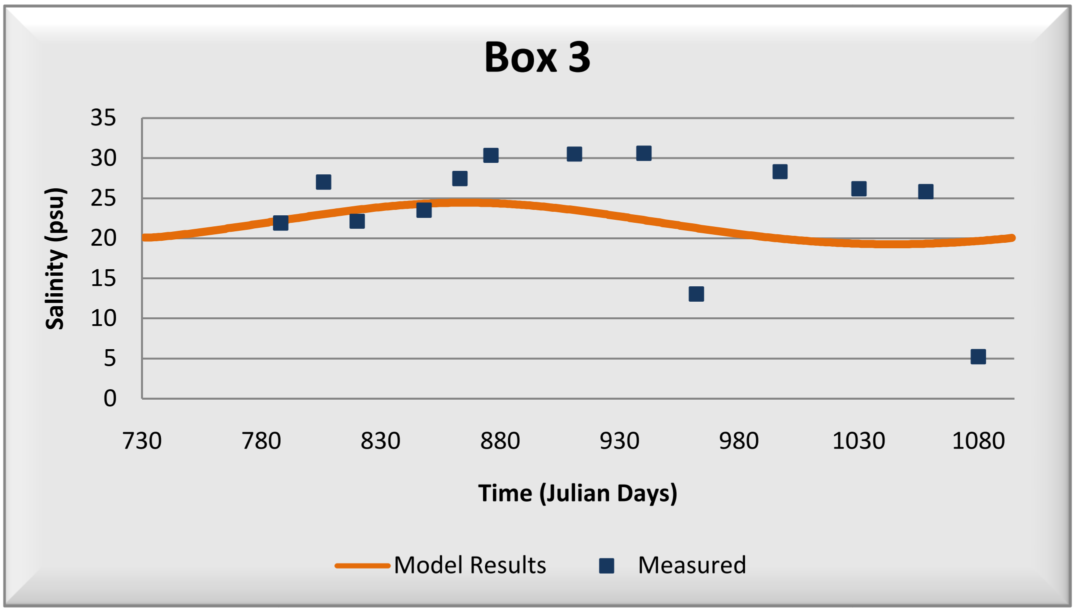

Figure 3.10 – Salinity: Model Calibration – Box 3

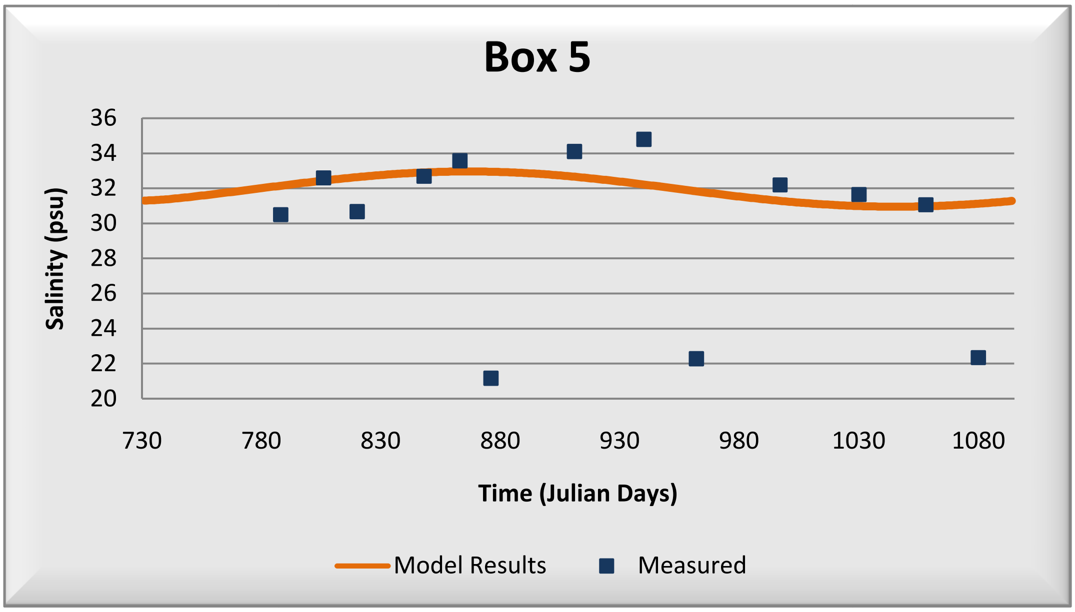

Figure 3.11 – Salinity: Model Calibration – Box 5

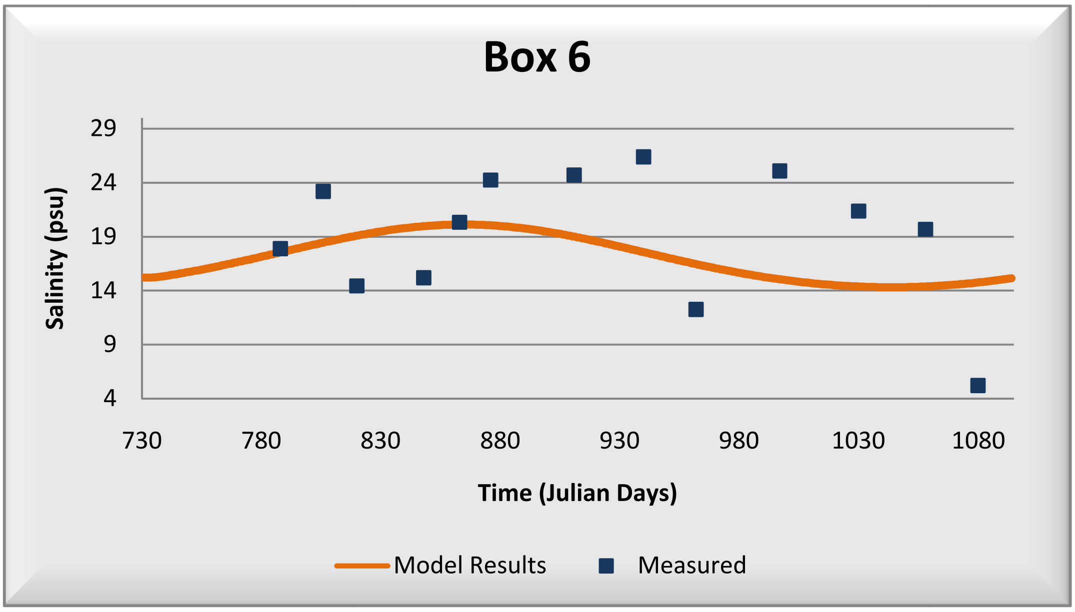

Figure 3.12 – Salinity: Model Calibration – Box 6

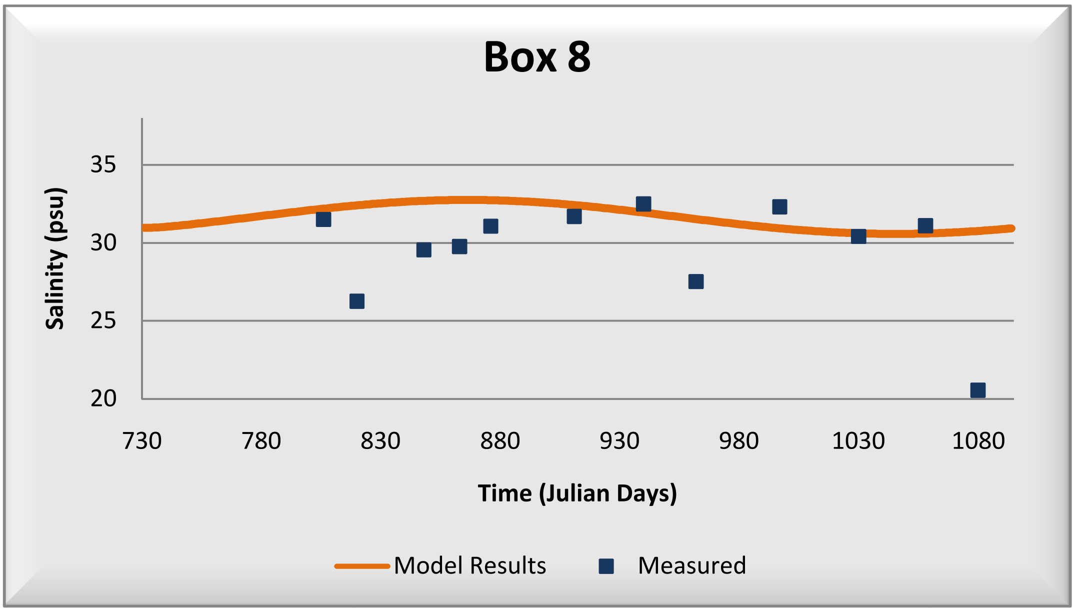

Figure 3.13 – Salinity: Model Calibration – Box 8

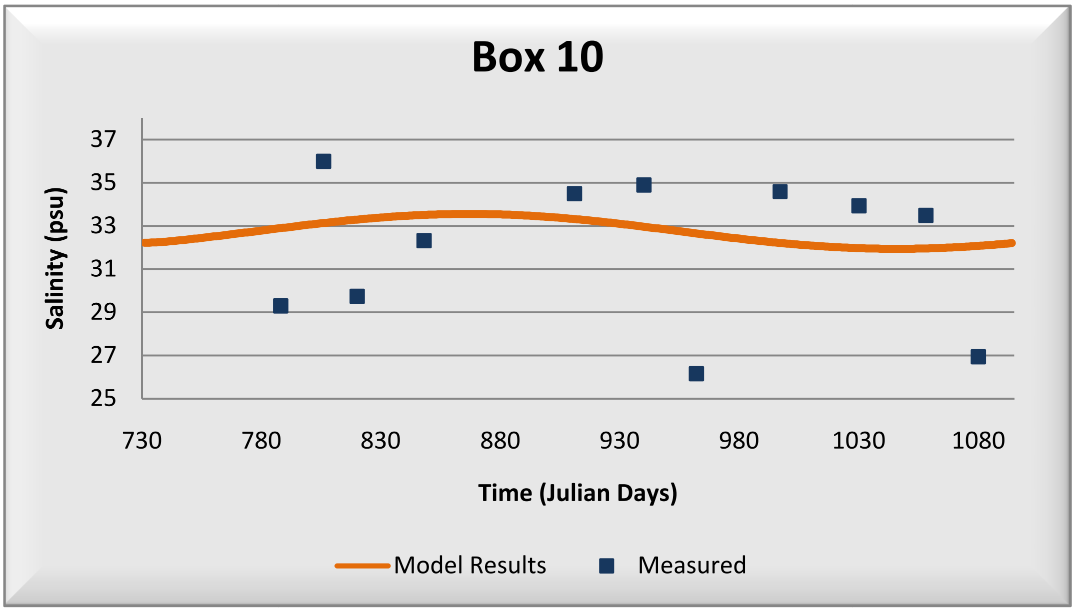

Figure 3.14 – Salinity: Model Calibration – Box 10

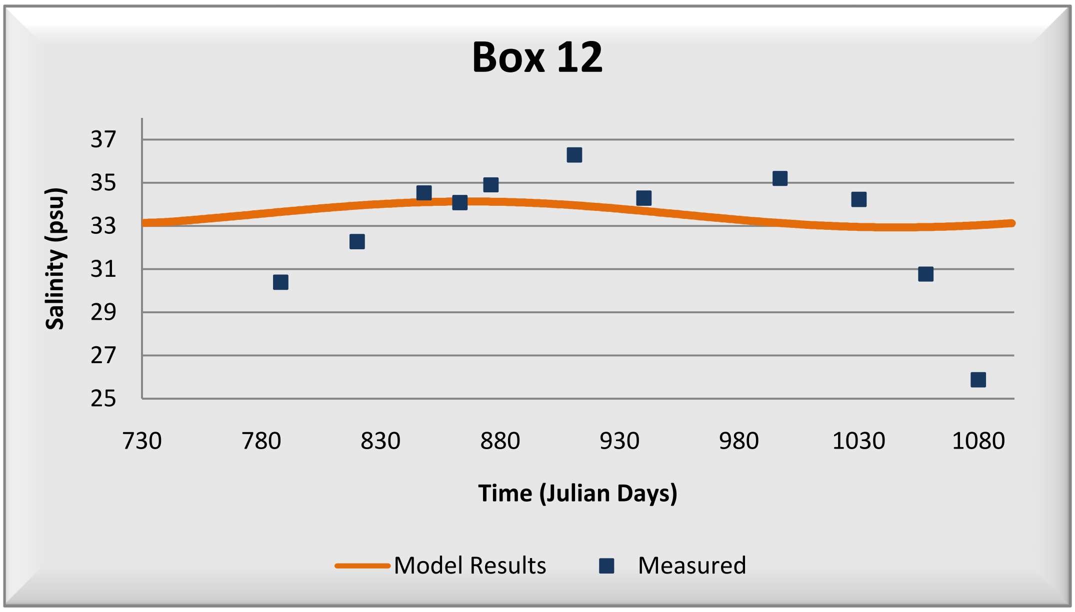

Figure 3.15 – Salinity: Model Calibration – Box 12

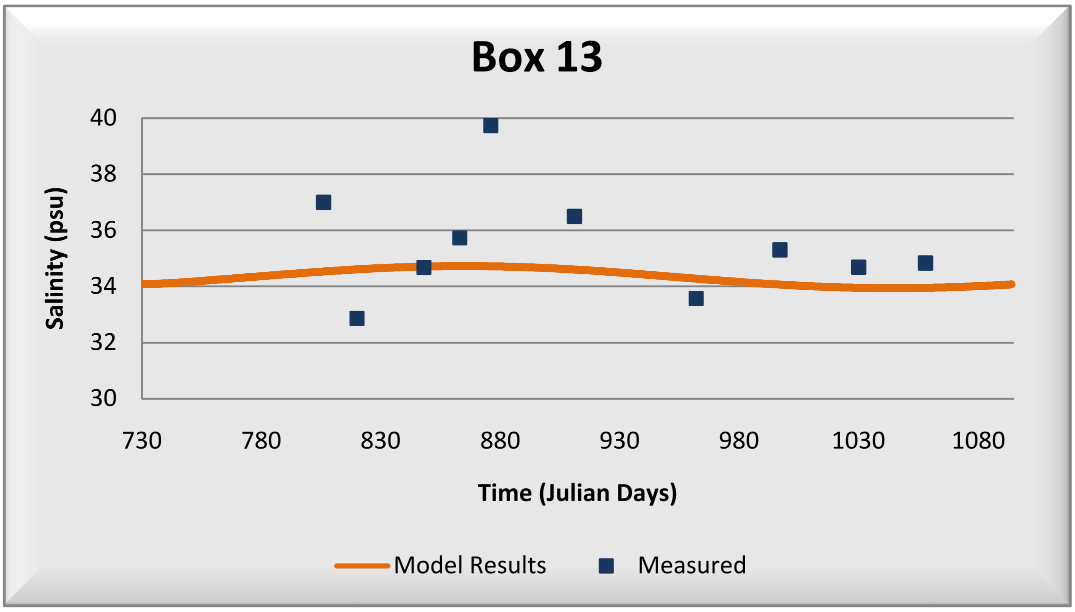

Figure 3.16 – Salinity: Model Calibration – Box 13

3.1.4. Suspended Particulate Matter (SPM)

The results of SPM calibration do not present a good correlation between model and measured data. This fact might result of variation from measured data along the year, like is shown in Figure 3.17, Figure 3.18, Figure 3.19, Figure 3.20, Figure 3.21, Figure 3.22, Figure 3.23 and Figure 3.24.

Although the results presented in Table 3.4, the model are considered as satisfying at the year scale.

Table 3.4 – Statistics Results – Suspended Particulate Matter Calibration

	Box 1	Box 3	Box 5	Box 6	Box 8	Box 10	Box 12	Box 13	Global
Relative Bias	17,4	24,1	19,5	0,4	23,3	12,2	5,2	5,4	13,5
Average Error (%)	58%	55%	37%	33%	40%	42%	51%	35%	44%
Correlation	0,19	0,61	-0,55	0,68	-0,67	-0,17	-0,05	-0,54	0,46

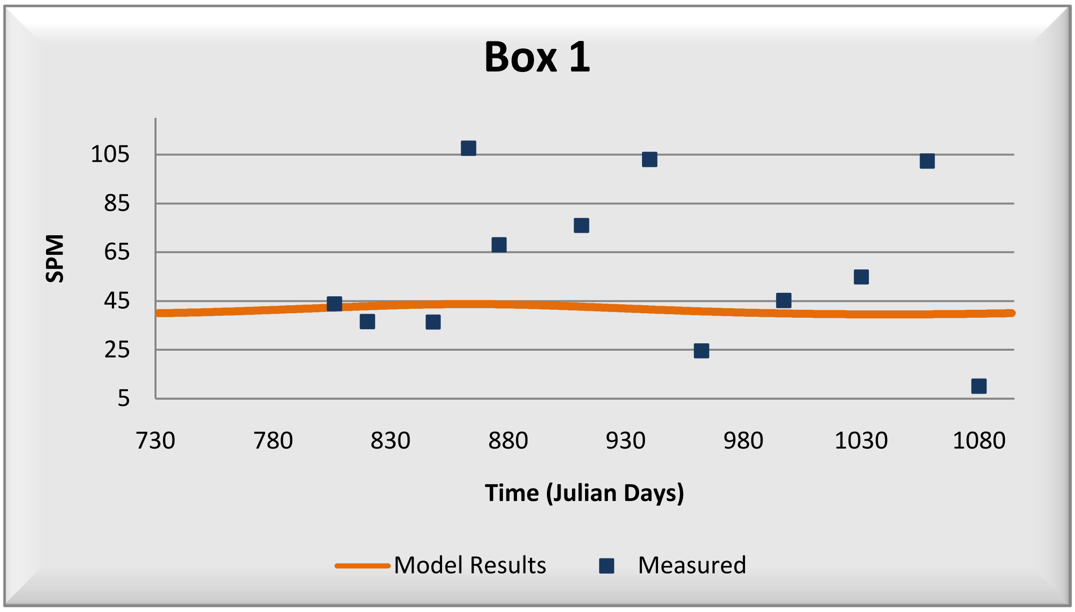

Figure 3.17 – SPM: Model Calibration – Box 1

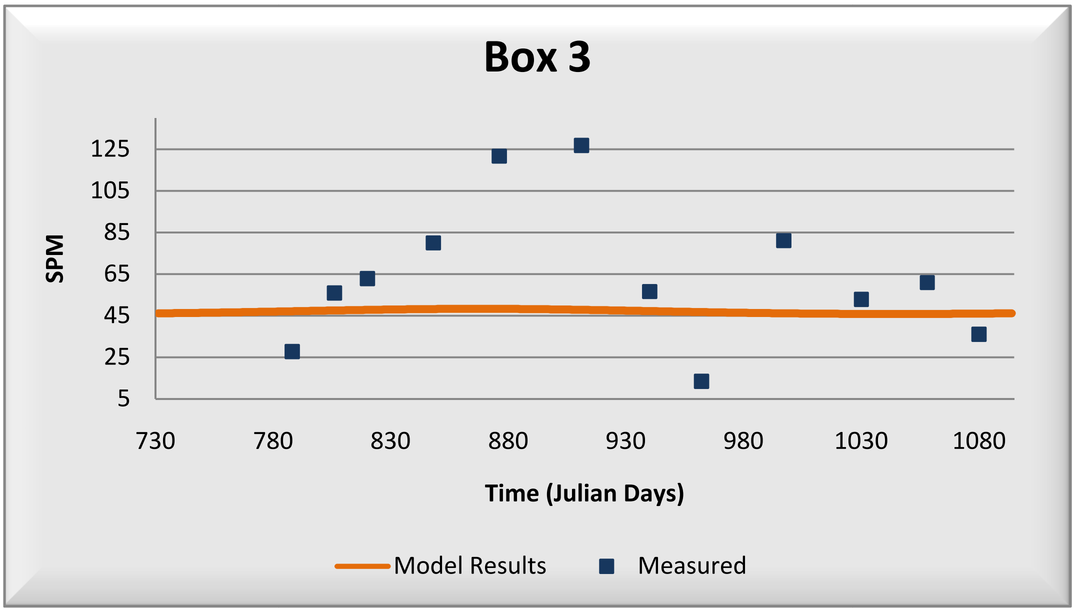

Figure 3.18 – SPM: Model Calibration – Box 3

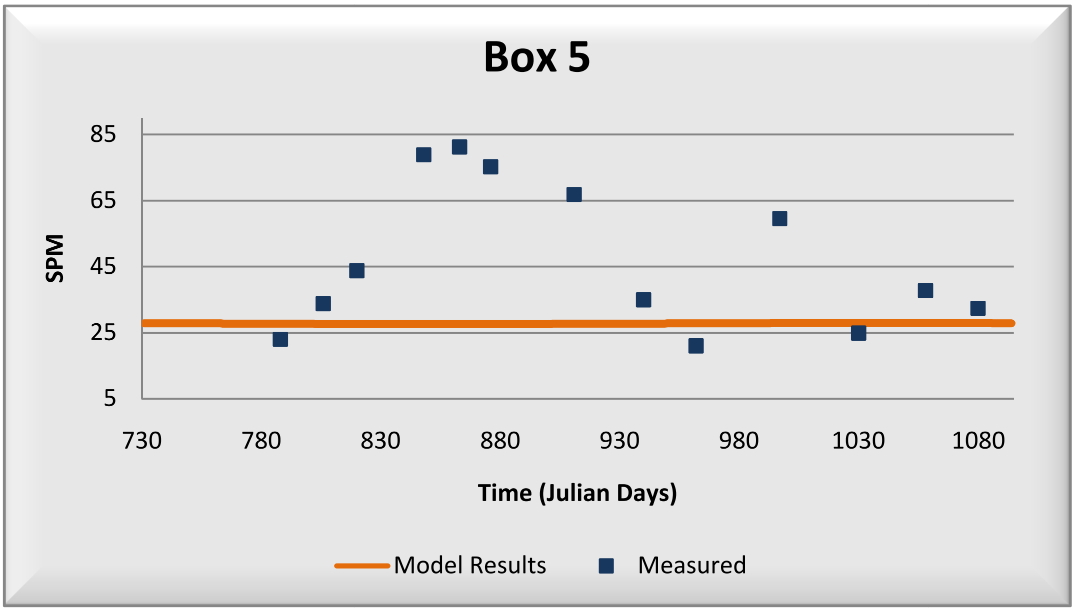

Figure 3.19 – SPM: Model Calibration – Box 5

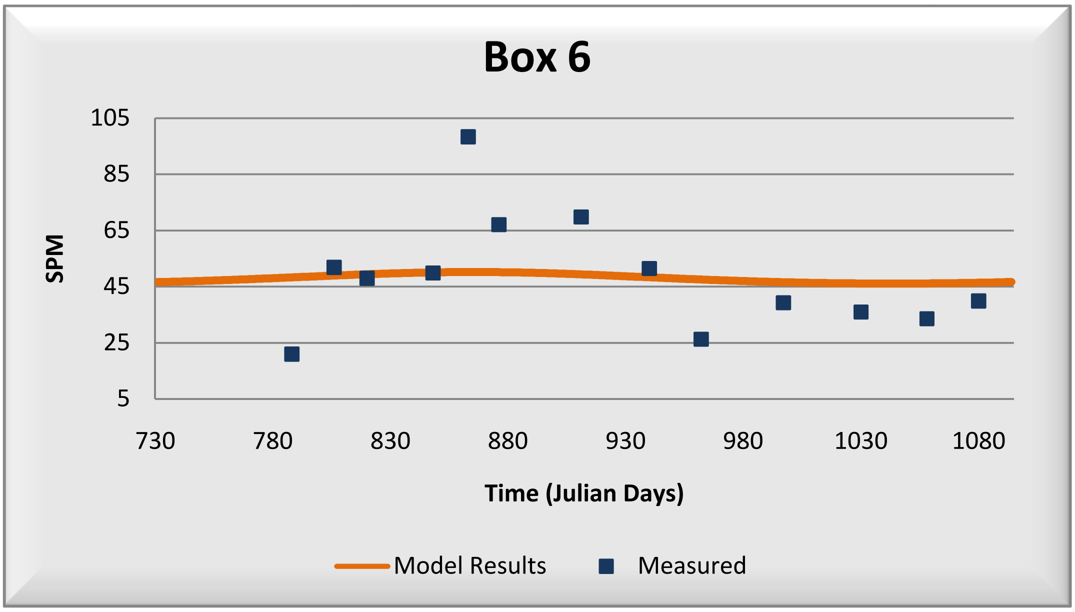

Figure 3.20 – SPM: Model Calibration – Box 6

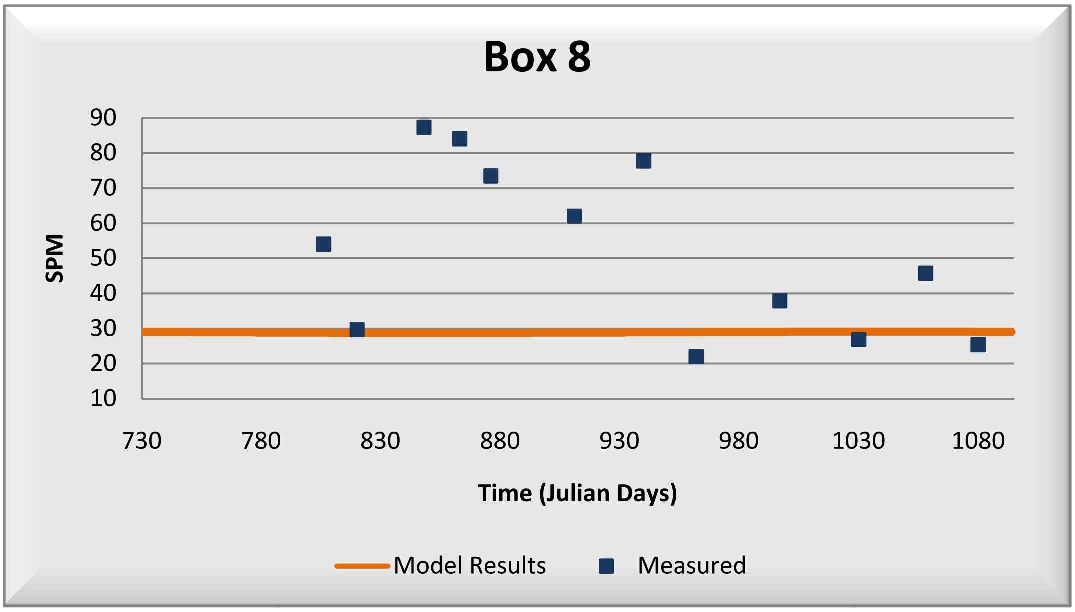

Figure 3.21 – SPM: Model Calibration – Box 8

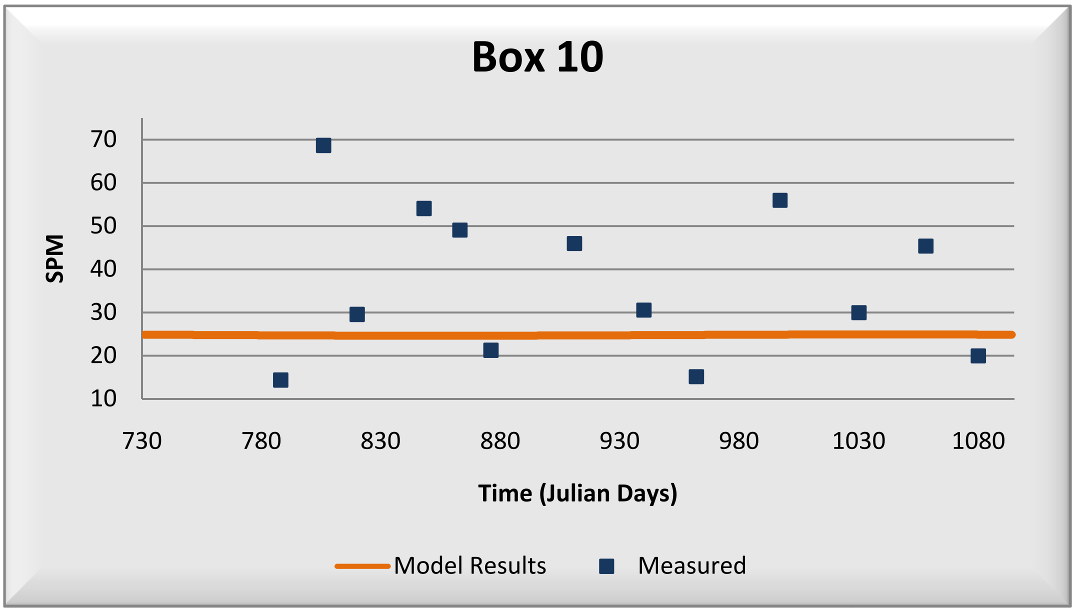

Figure 3.22 – SPM: Model Calibration – Box 10

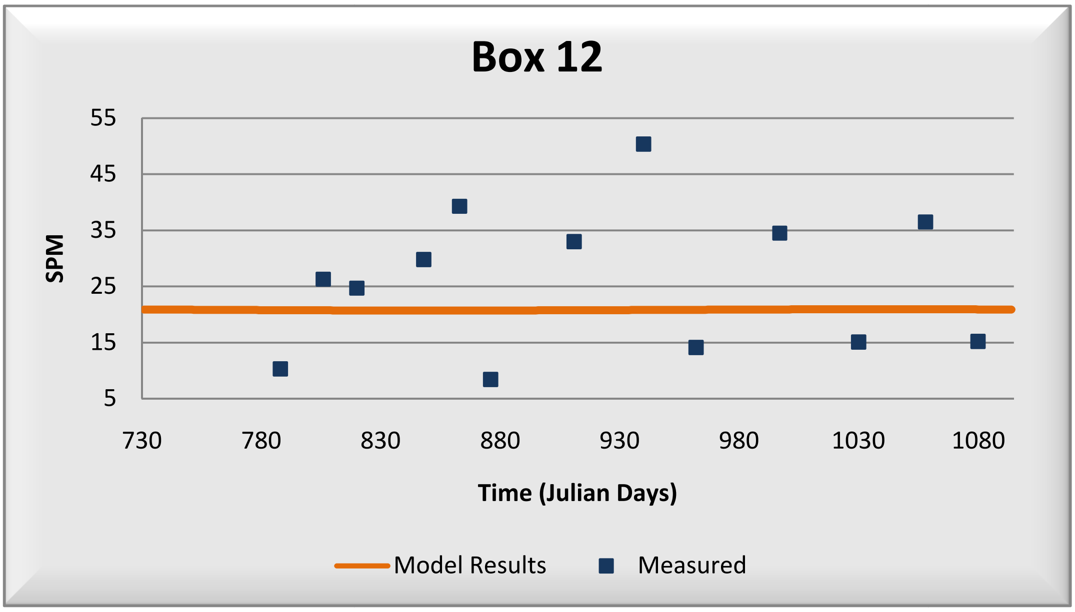

Figure 3.23 – SPM: Model Calibration – Box 12

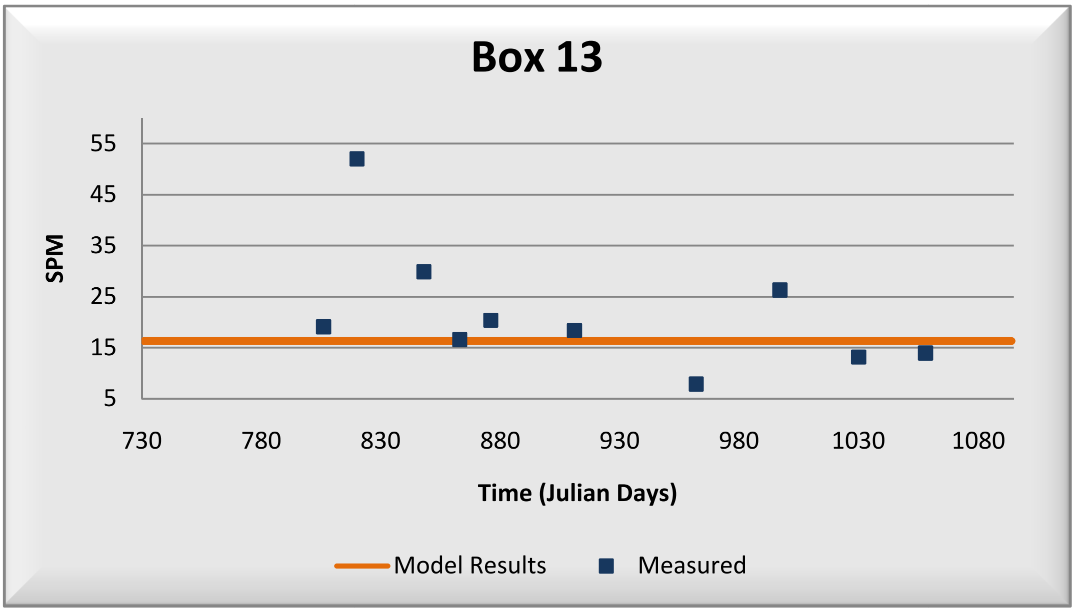

Figure 3.24 – SPM: Model Calibration – Box 13

3.1.5. Phytoplankton

The correlation between model results and measured data, even though the huge errors values presented in Table 3.5, are considerably good.

Table 3.5 – Statistics Results – Phytoplankton Calibration

	Box 1	Box 3	Box 5	Box 6	Box 8	Box 10	Box 12	Global
Relative Bias	11,5	-1,2	3,1	-0,6	1,6	6,4	5,7	3,8
Average Error (%)	56%	59%	62%	102%	64%	53%	77%	68%
Correlation	0,55	0,63	0,34	0,63	0,45	0,61	0,52	0,52

The variation of phytoplankton biomass is presented in Figure 3.25, Figure 3.26, Figure 3.27, Figure 3.28, Figure 3.29, Figure 3.30 and Figure 3.31, where it is possible seen the increase of chl a in springs illustrating the bloom.

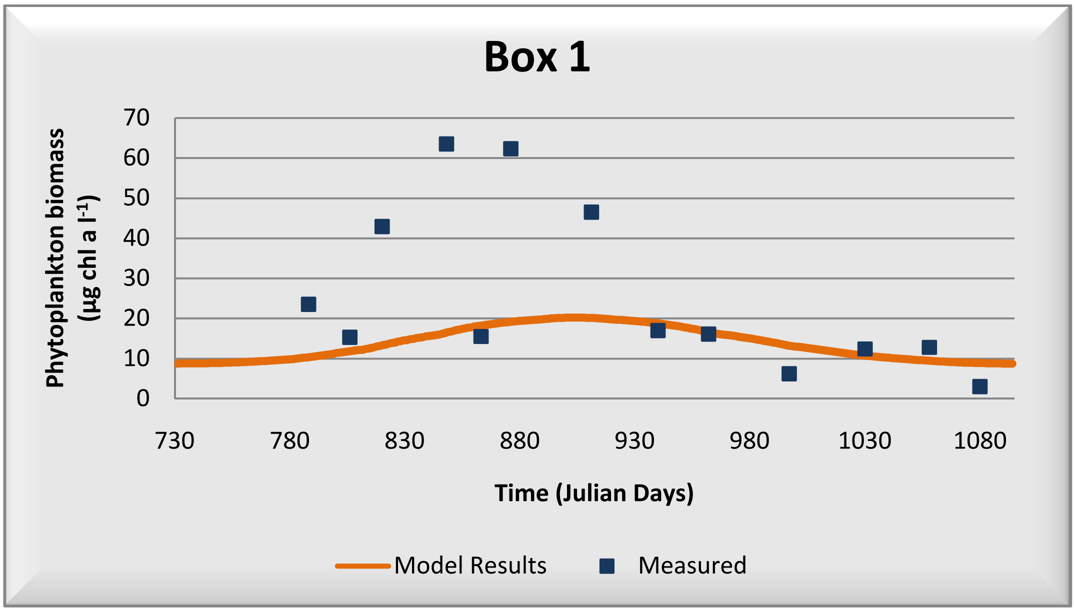

Figure 3.25 – Phytoplankton: Model Calibration – Box 1

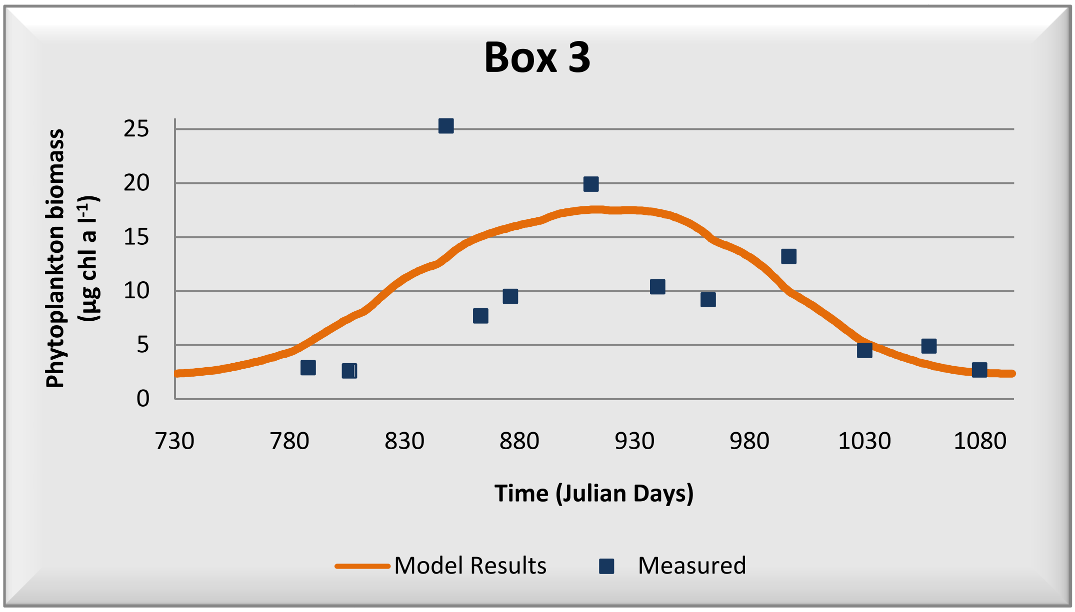

Figure 3.26 – Phytoplankton: Model Calibration – Box 3

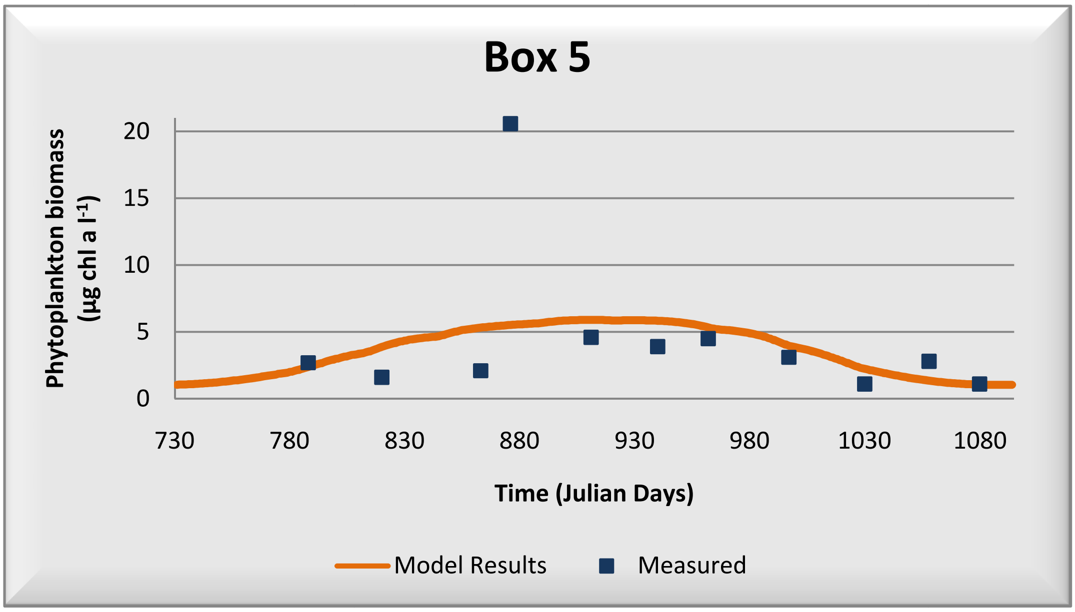

Figure 3.27 – Phytoplankton: Model Calibration – Box 5

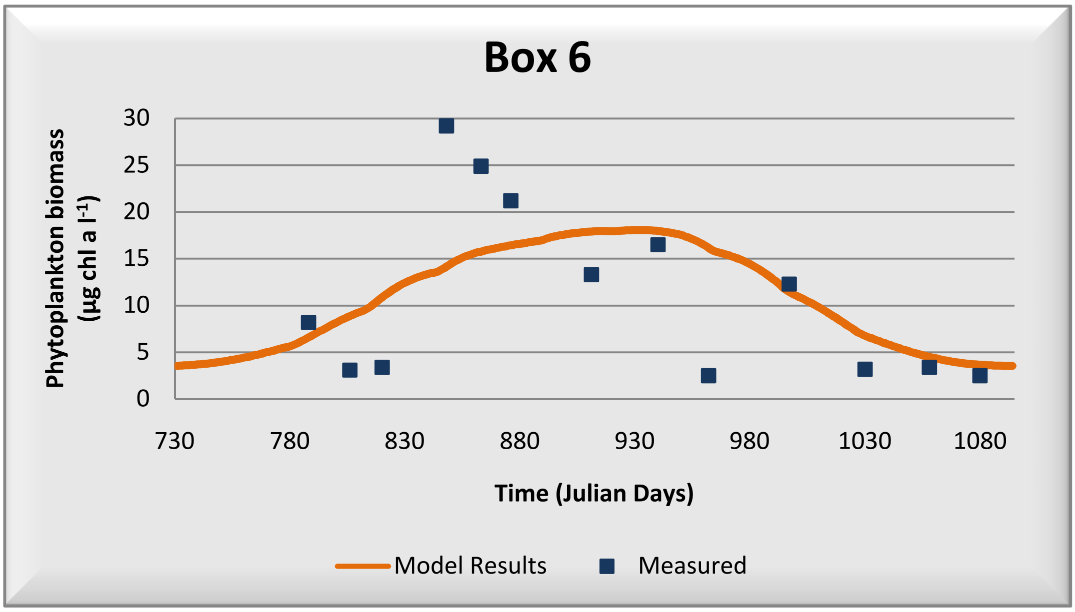

Figure 3.28 – Phytoplankton: Model Calibration – Box 6

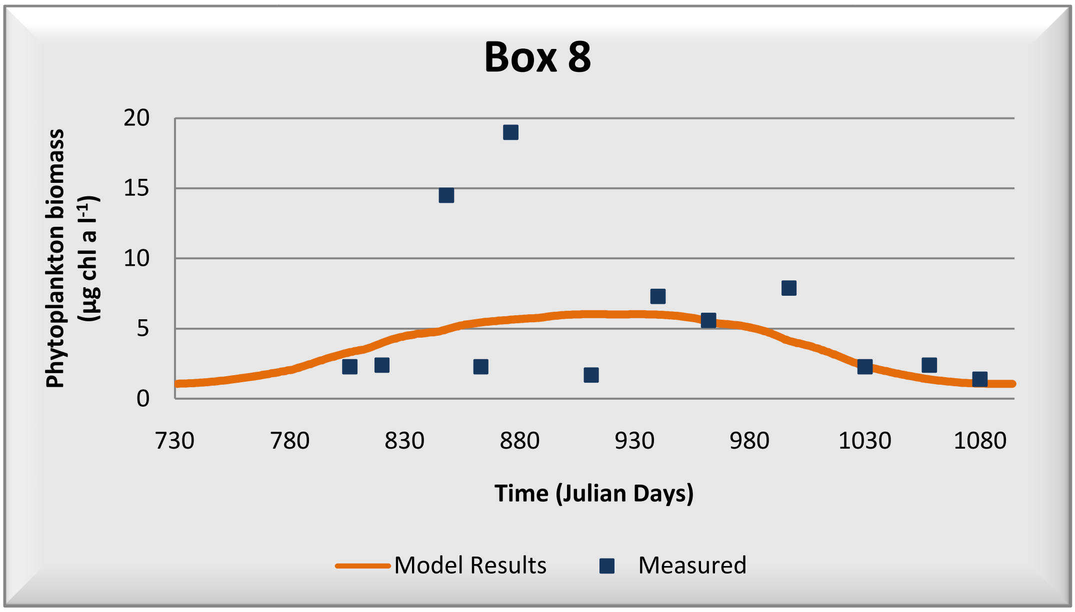

Figure 3.29 – Phytoplankton: Model Calibration – Box 8

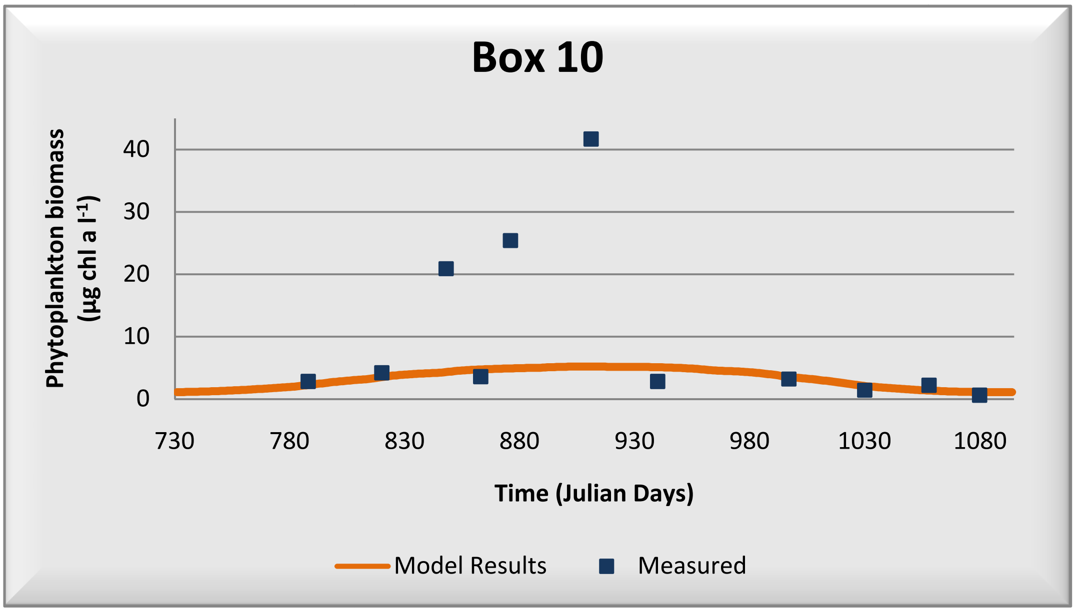

Figure 3.30 – Phytoplankton: Model Calibration – Box 10

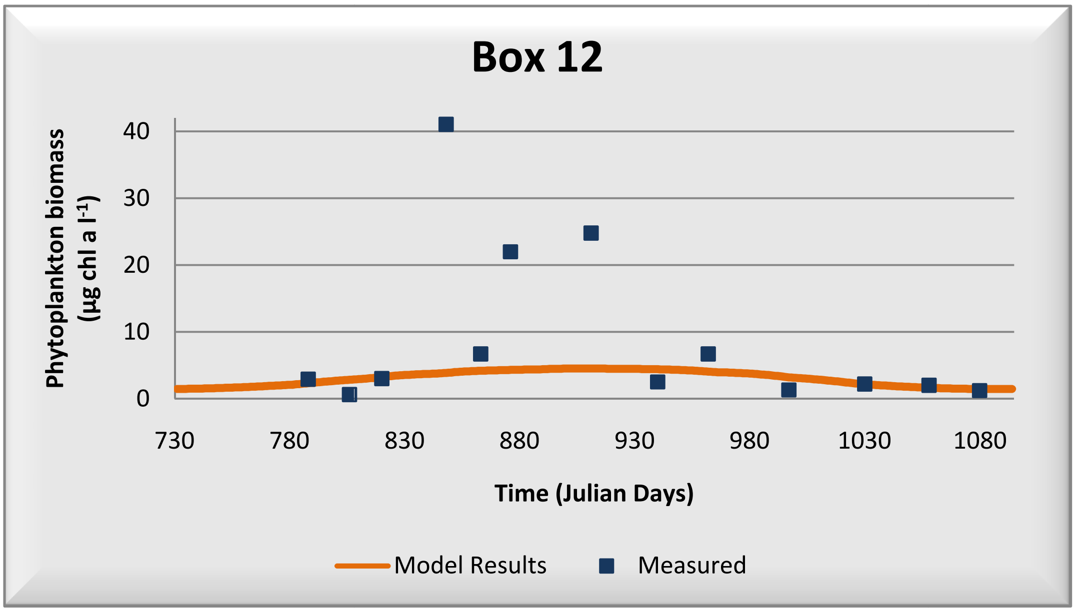

Figure 3.31 – Phytoplankton: Model Calibration – Box 12

3.1.6. Zoobenthos

After calibration it can be seen in Figure 3.32 and Figure 3.33 that the model results tend to overestimate oyster growth in box 4 and 6. Because the same parameters are used to simulate the oyster growth in all boxes, any change to get better box 4 and 6 results would tend to underestimate oyster growth in the others.

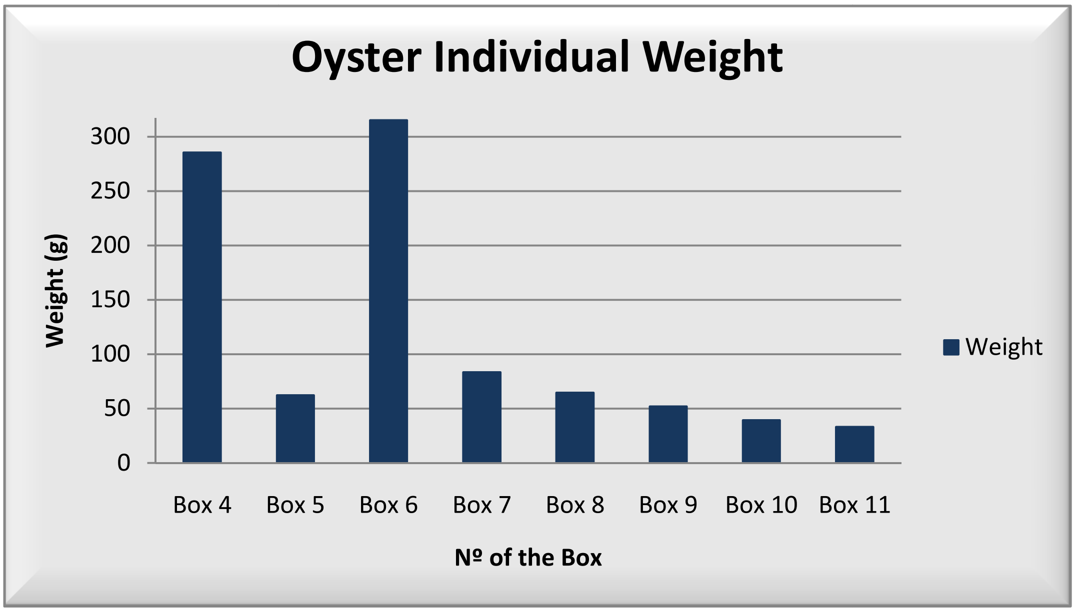

Figure 3.32 – Oyster individual weight

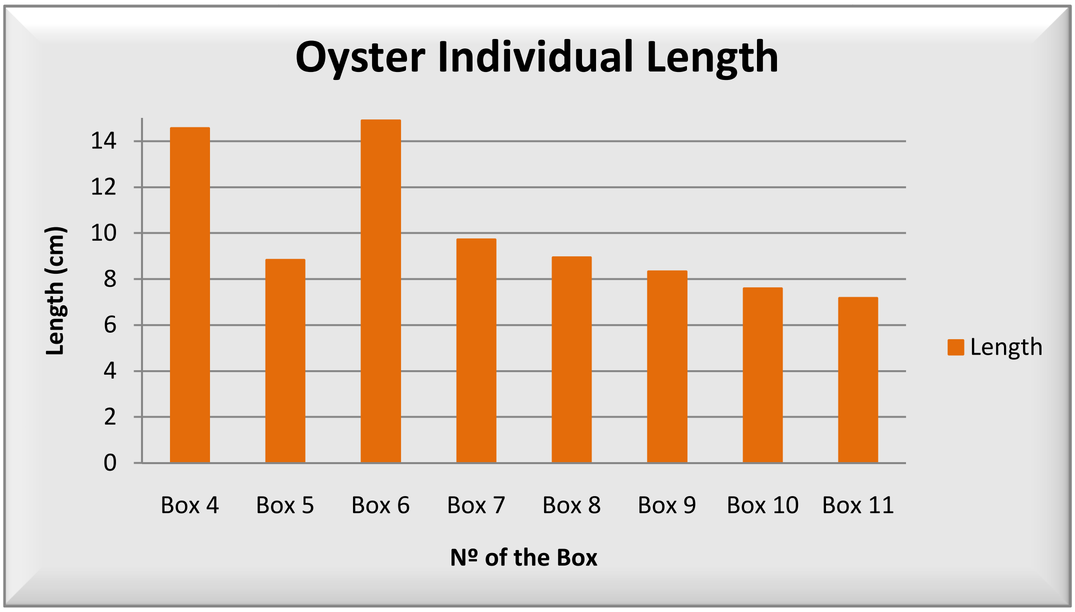

Figure 3.33 – Oyster individual length

At the end of third year of calibration, the total oysters harvested for each box are illustrated in Figure 3.34. It is shown that in boxes 6, 7 and 8 the production is higher than in the others.

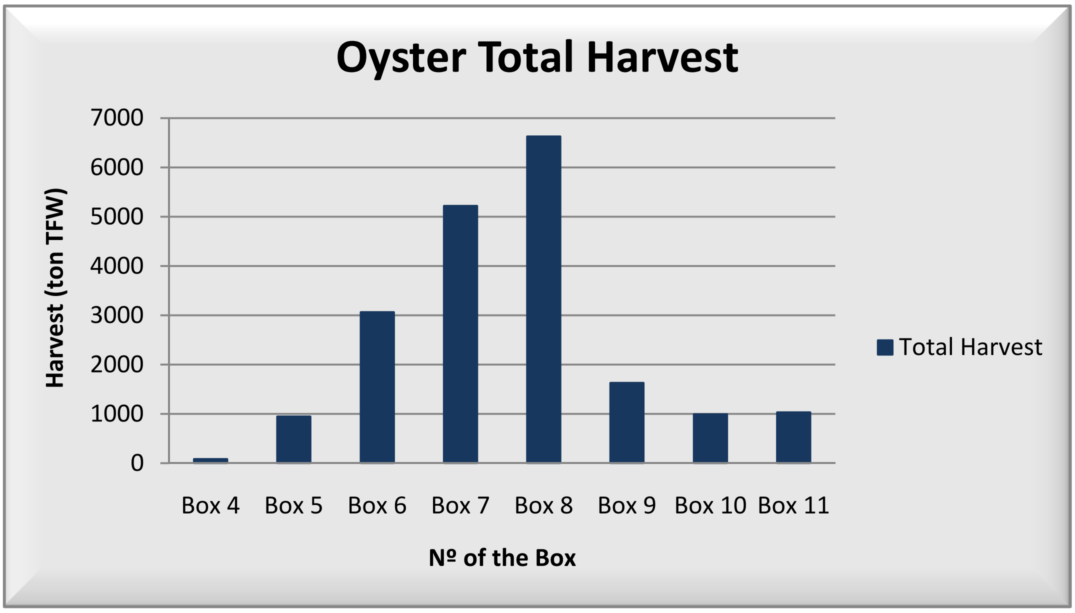

Figure 3.34 – Oyster total harvest

3.2. Validation

3.2.1. Water Temperature

The model results for water temperature were compared to the measured water temperature of the Database 1982 - Figure 3.35, Figure 3.36, Figure 3.37, Figure 3.38 and Figure 3.39. Because of the model results still presents a good correlation with field data (Table 3.6) this forcing function was not recalibrated for the validation of the model.

Table 3.6 – Statistics Results – Water Temperature Validation

	Box 1	Box 6	Box 8	Box 10	Box 12	Global
Relative Bias	2,0	0,5	0,2	-0,8	-1,3	0,3
Average Error (%)	12%	15%	10%	13%	17%	13%
Correlation	0,94	0,68	0,95	0,96	0,91	0,80

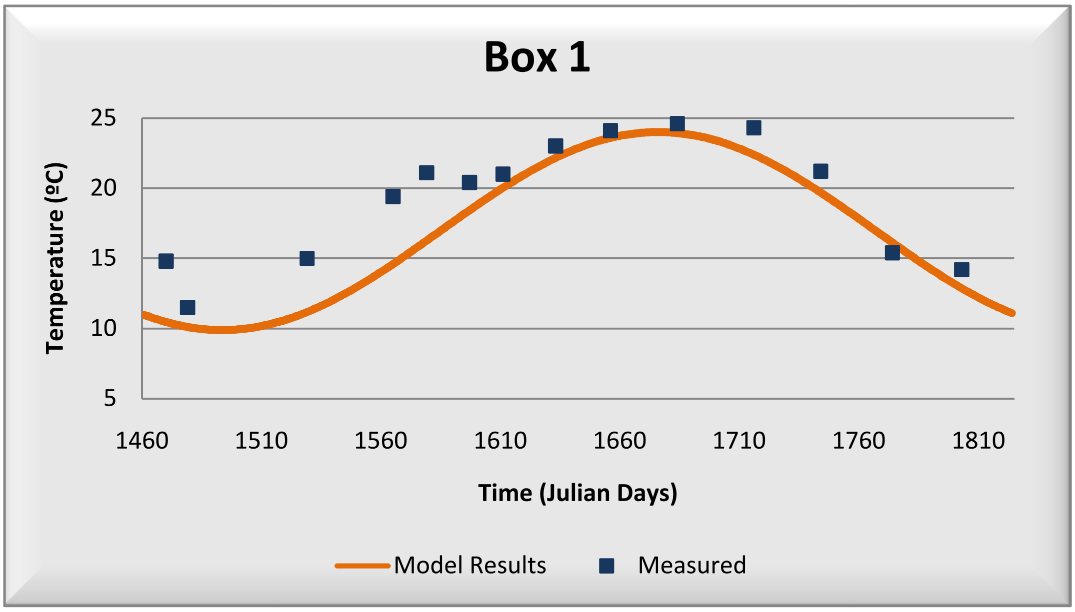

Figure 3.35 – Water Temperature: Model Validation – Box 1

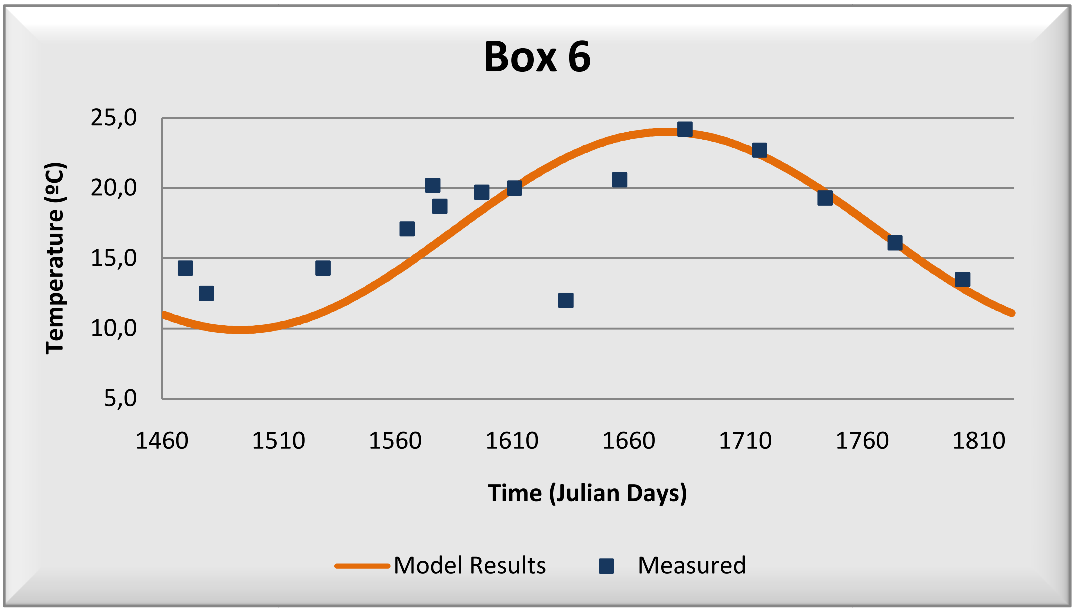

Figure 3.36 – Water Temperature: Model Validation – Box 6

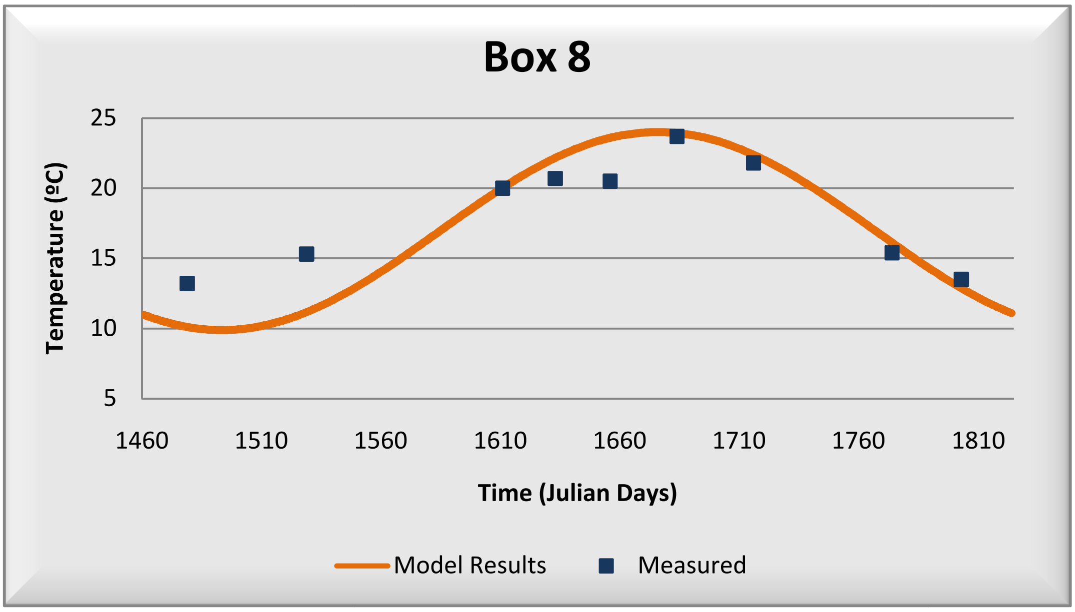

Figure 3.37 – Water Temperature: Model Validation – Box 8

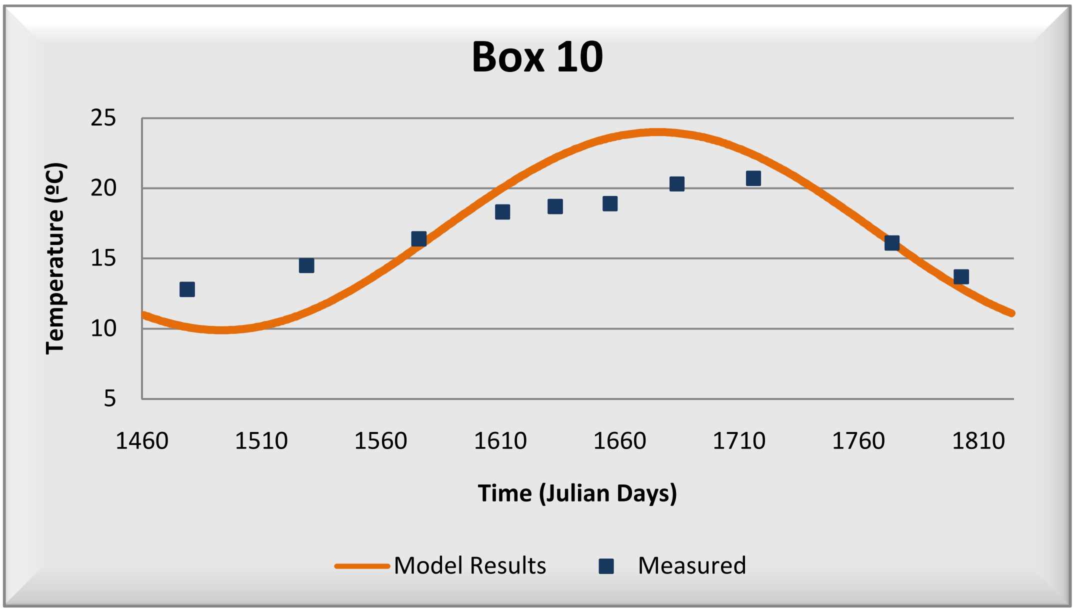

Figure 3.38 – Water Temperature: Model Validation – Box 10

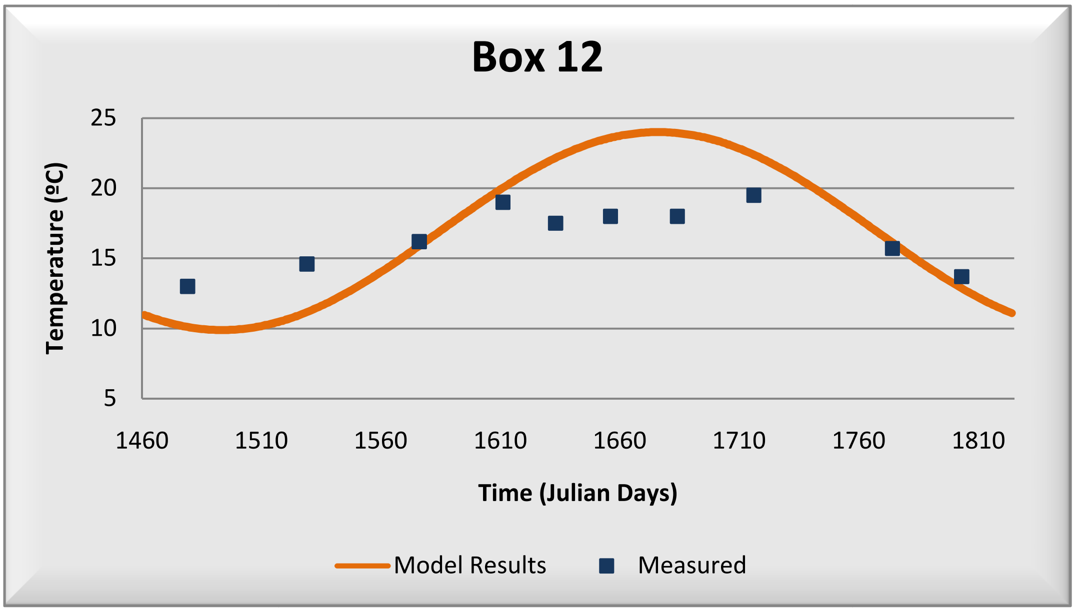

Figure 3.39 – Water Temperature: Model Validation – Box 12

3.2.2. Salinity

Like it was happened in salinity calibration, in validation, the global correlation is good and percentage of errors is not relevant (Table 3.7), so that this state variable is not recalibrated for the validation model.

Table 3.7 – Statistics Results – Salinity Validation

	Box 6	Box 8	Box 10	Box 12	Global
Relative Bias	3,6	-1,4	-3,5	-2,6	-0,8
Average Error (%)	25%	8%	18%	14%	17%
Correlation	0,18	0,55	0,22	-0,47	0,70

In Figure 3.40, Figure 3.41, Figure 3.42 and Figure 3.43 are shown the model results and measured data for salinity validation.

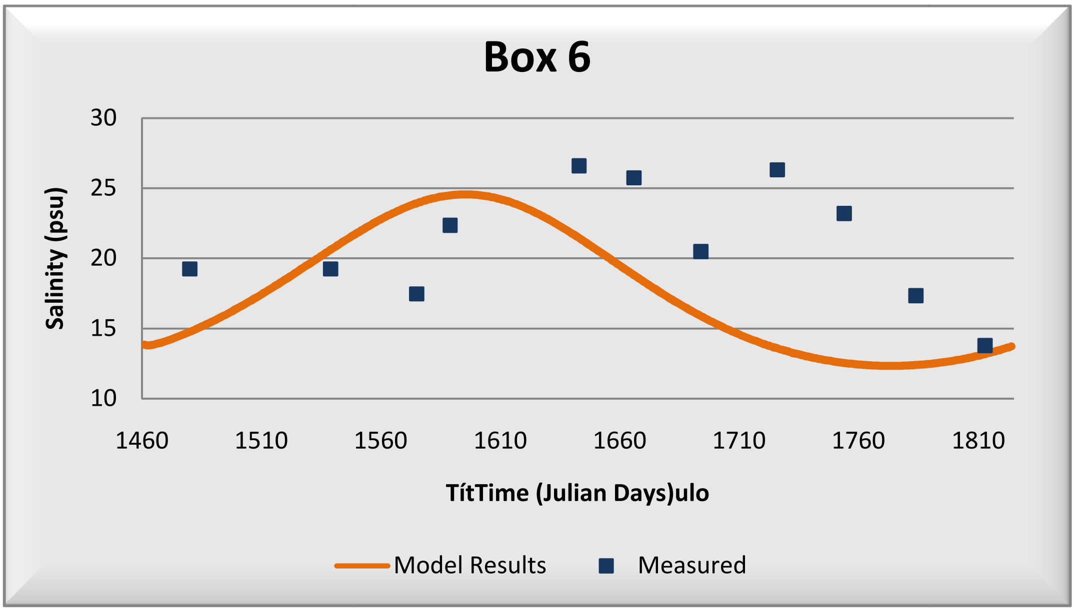

Figure 3.40 – Salinity: Model Validation – Box 6

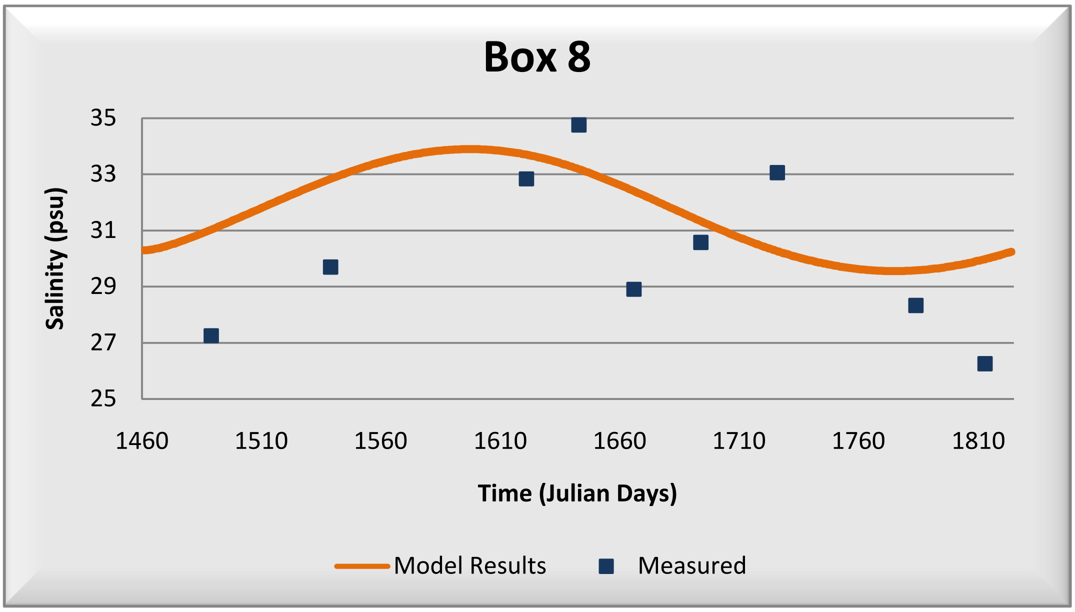

Figure 3.41 – Salinity: Model Validation – Box 8

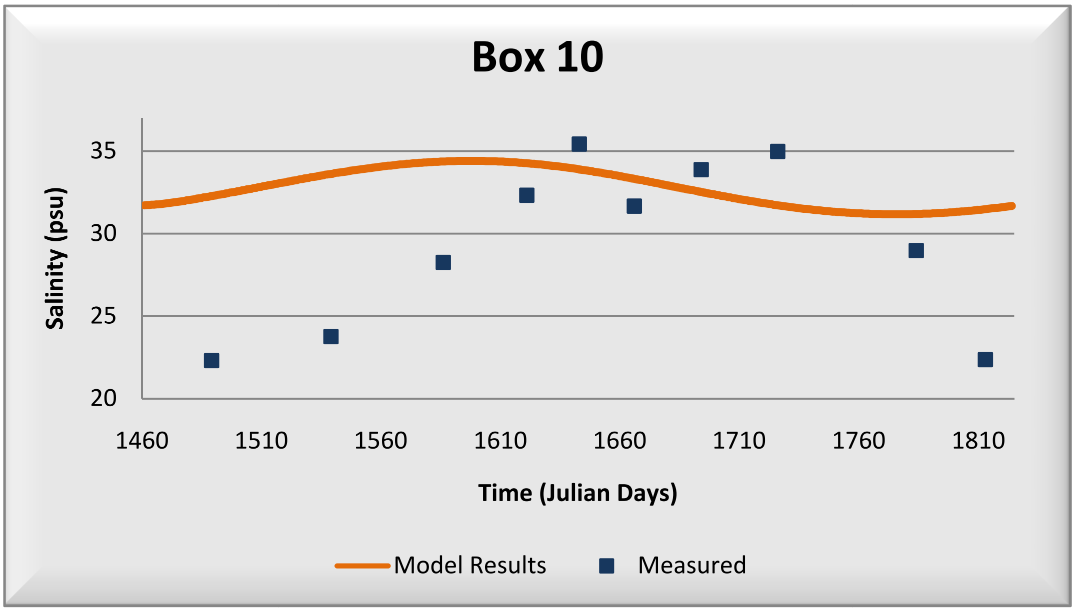

Figure 3.42 – Salinity: Model Validation – Box 10

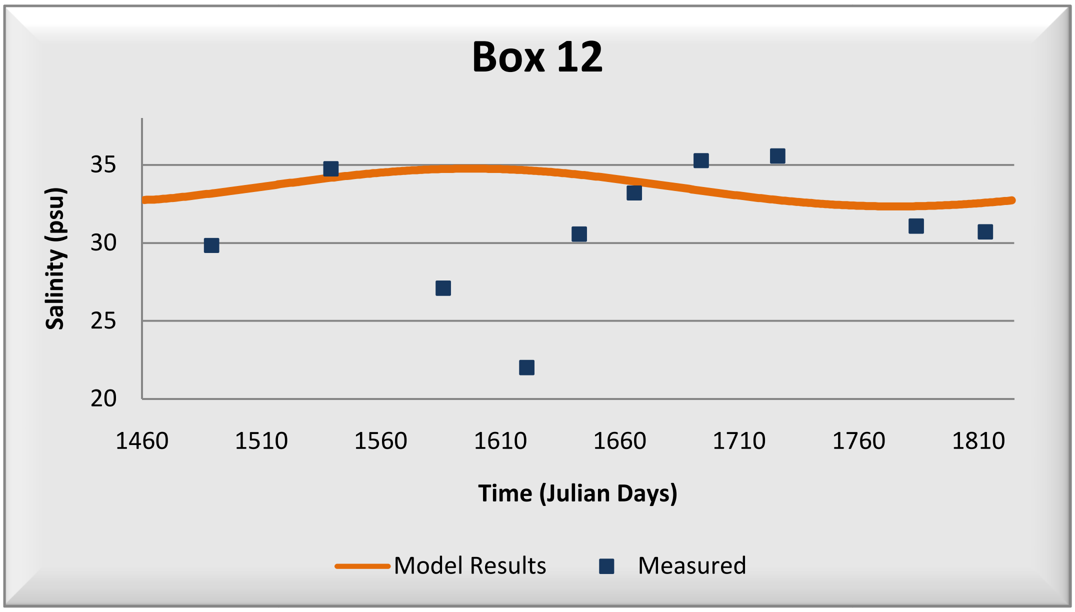

Figure 3.43 – Salinity: Model Validation – Box 12

3.2.3. Suspended Particulate Matter

For this state variable, the conclusion is the same that it was in calibration, the model presents satisfactory results at the year scale. The outcomes for the quantitative validation are shown in table below (Table 3.8).

Table 3.8 – Statistics Results – Suspended Particulate Matter Validation

	Box 1	Box 6	Box 8	Box 10	Box 12	Global
Relative Bias	18,1	8,9	13,7	7,1	1,0	10,1
Average Error (%)	39%	33%	51%	35%	24%	36%
Correlation	-0,42	-0,07	-0,55	0,01	0,09	0,45

The model results and measured data are illustrated for respectively boxes in Figure 3.44, Figure 3.45, Figure 3.46, Figure 3.47 and Figure 3.48.

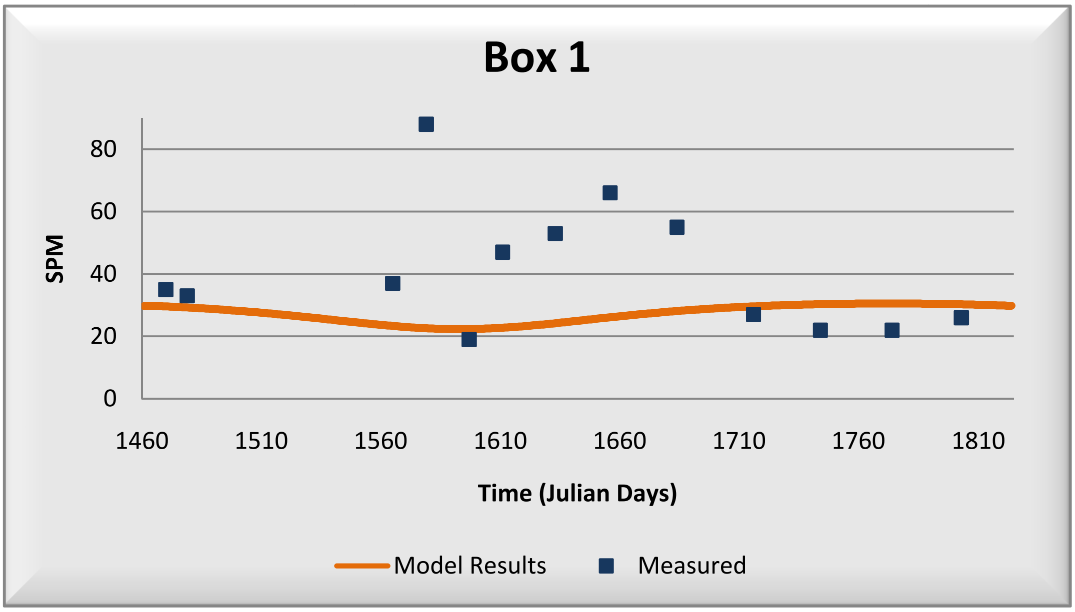

Figure 3.44 – SPM: Model Validation – Box 1

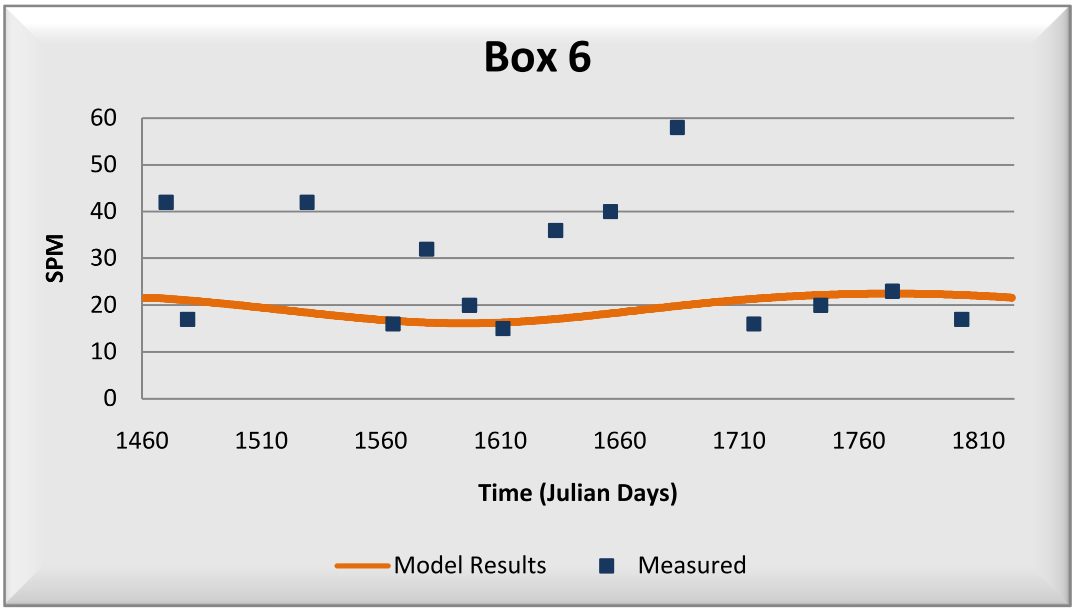

Figure 3.45 – SPM: Model Validation – Box 6

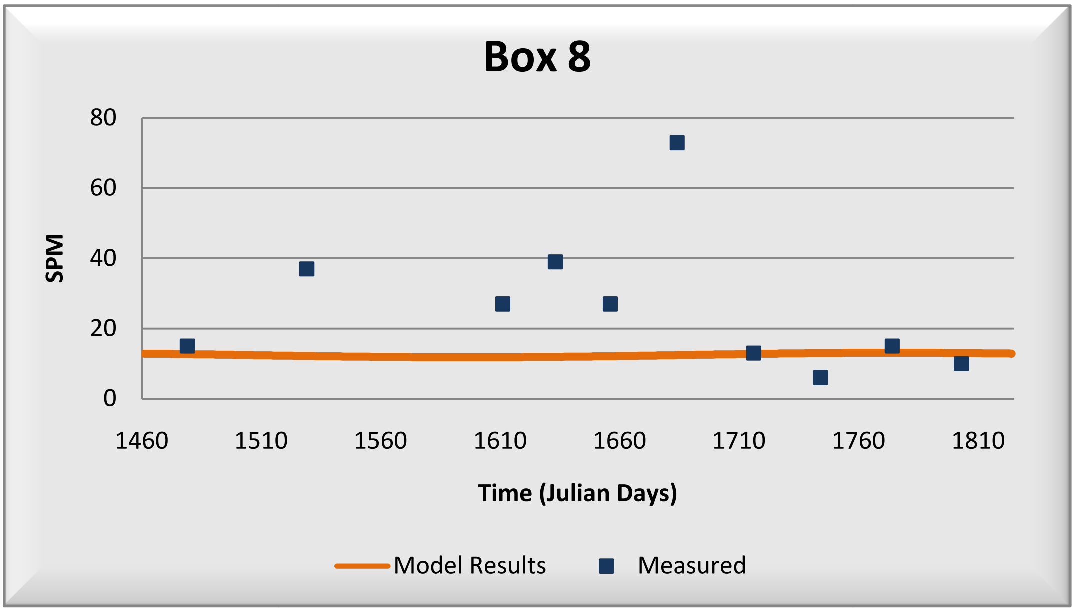

Figure 3.46 – SPM: Model Validation – Box 8

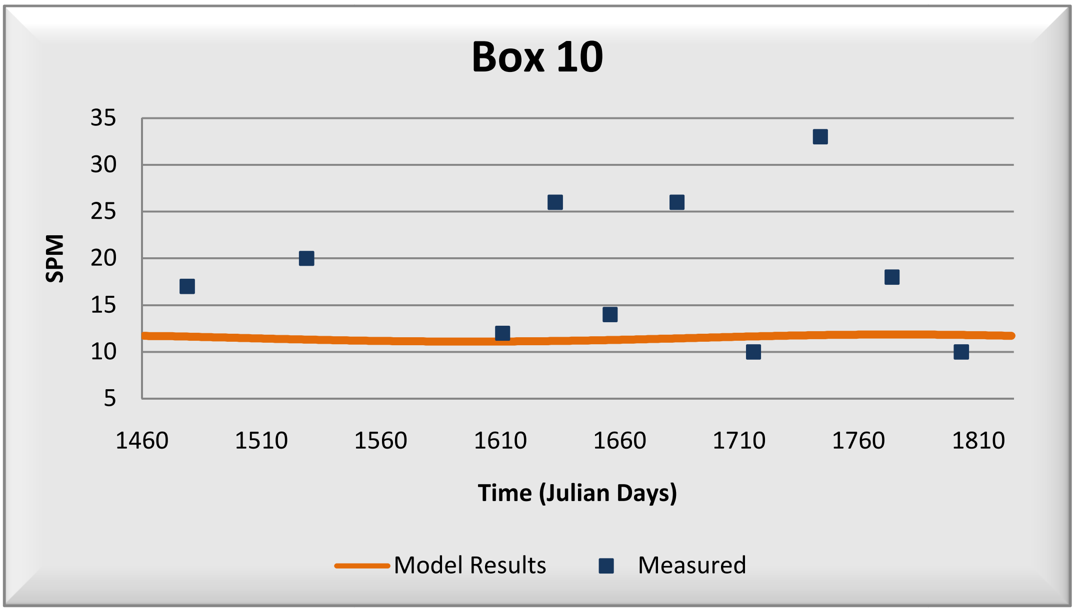

Figure 3.47 – SPM: Model Validation – Box 10

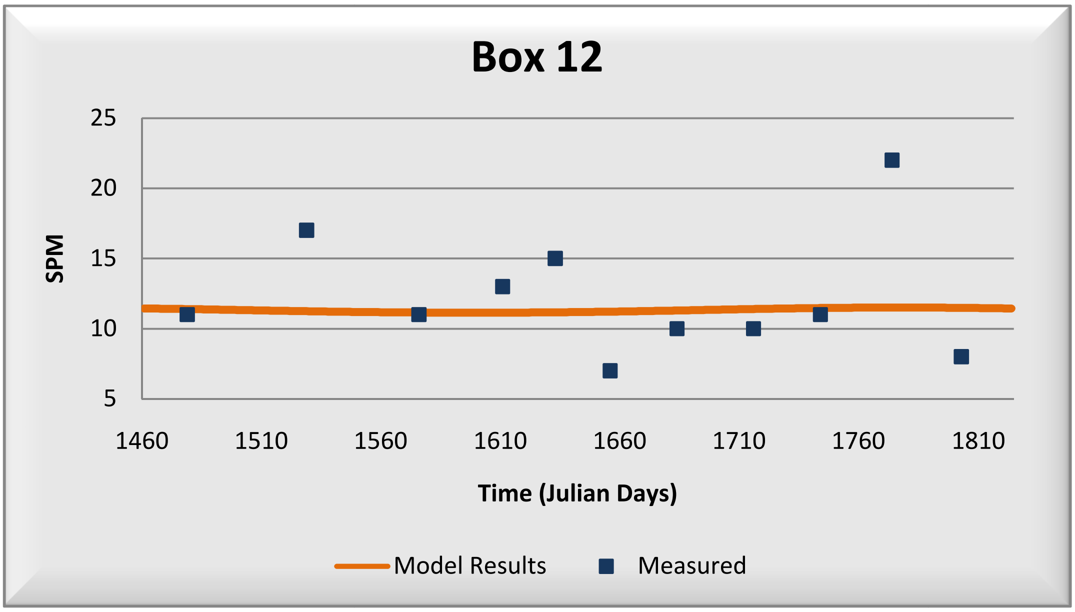

Figure 3.48 – SPM: Model Validation – Box 12

3.2.4. Phytoplankton

For the phytoplankton biomass validation is not considered the average error because, as it is illustrated in Figure 3.49, Figure 3.50, Figure 3.51, Figure 3.52 and Figure 3.53 the difference between model results and measured data are significantly, which probably is caused by the absence of the zooplankton in this ecological model. Despite this fact, the correlation and relative bias are good (Table 3.9) and the model represents well the algae bloom in the spring.

Table 3.9 – Statistics Results – Phytoplankton Validation

	Box 1	Box 6	Box 8	Box 10	Box 12	Global
Relative Bias	-8,0	-6,9	-0,4	-1,3	-1,4	-4,1
Correlation	0,41	0,69	0,61	0,47	0,65	0,61

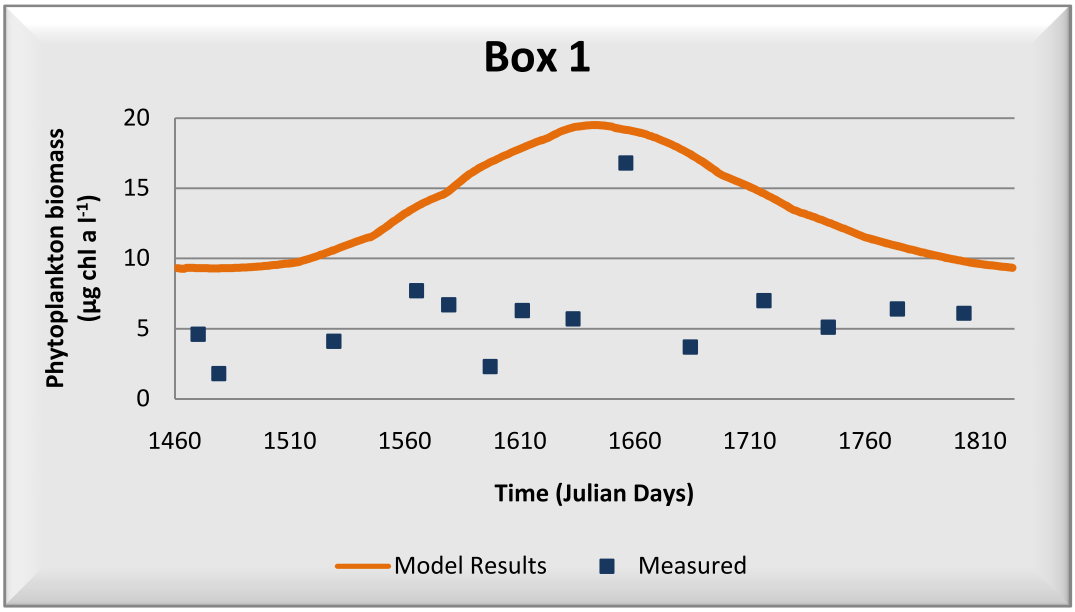

Figure 3.49 – Phytoplankton: Model Validation – Box 1

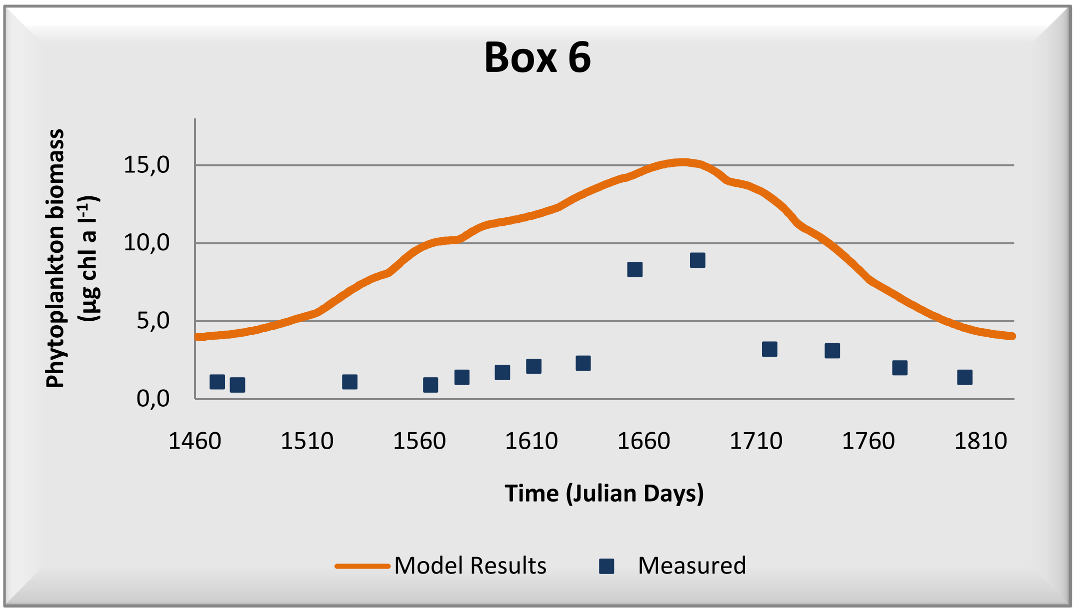

Figure 3.50 – Phytoplankton: Model Validation – Box 6

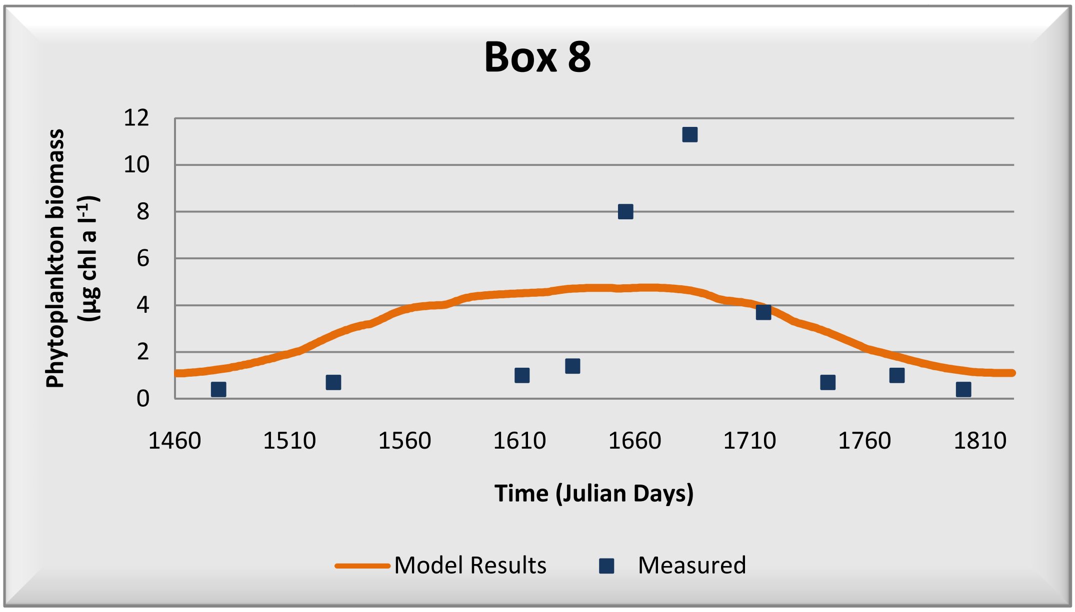

Figure 3.51 – Phytoplankton: Model Validation – Box 8

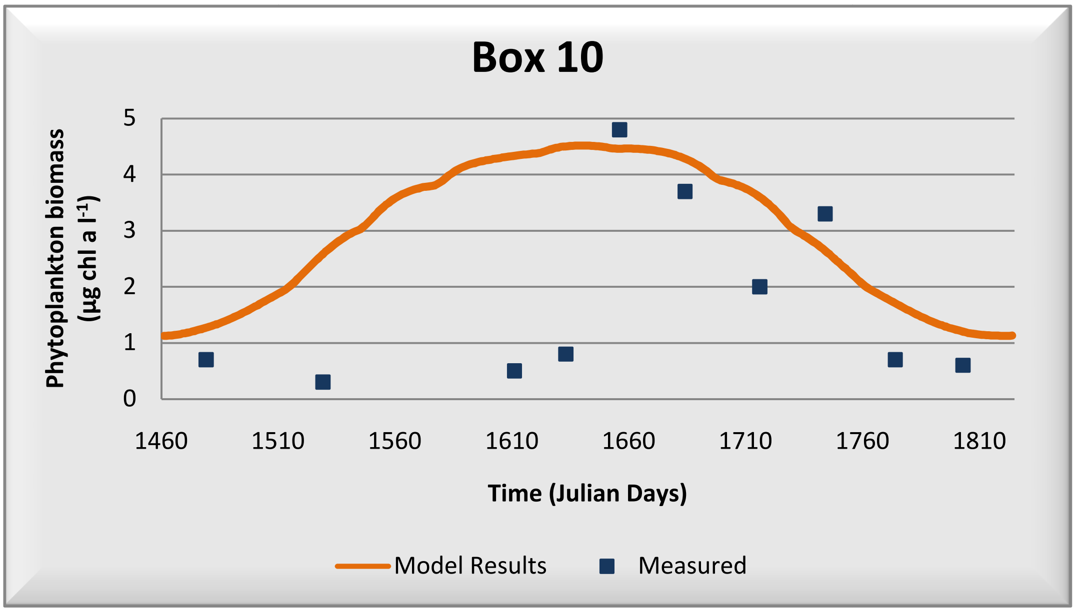

Figure 3.52 – Phytoplankton: Model Validation – Box 10

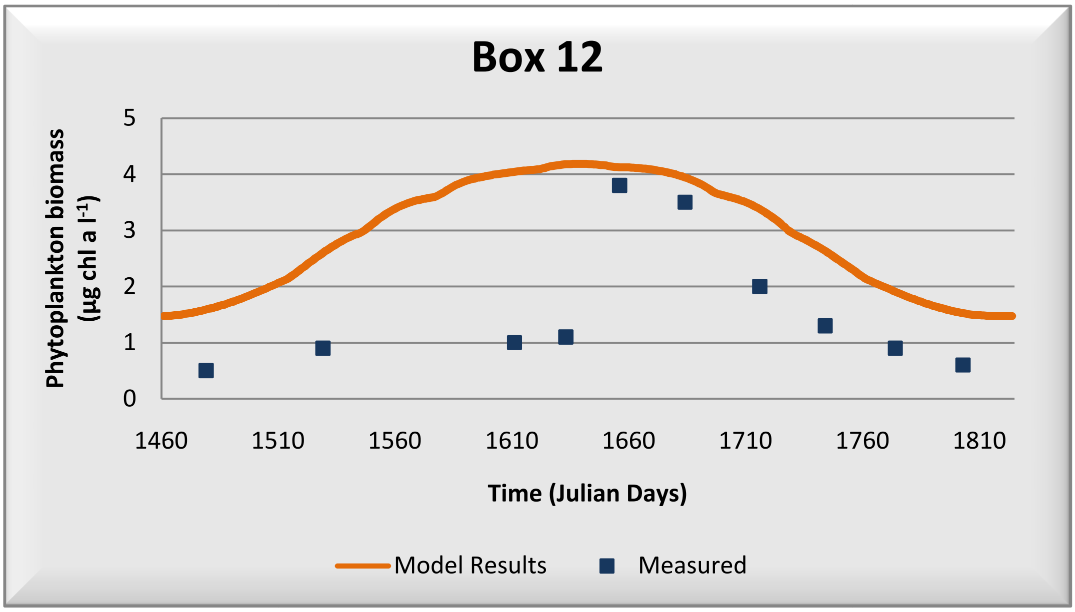

Figure 3.53 – Phytoplankton: Model Validation – Box 12

3.2.5. Zoobenthos

According to Figure 3.54 and Figure 3.55, boxes 4 and 6 continuing to present higher values of oyster individual weight and length than the others like as it happened in calibration.

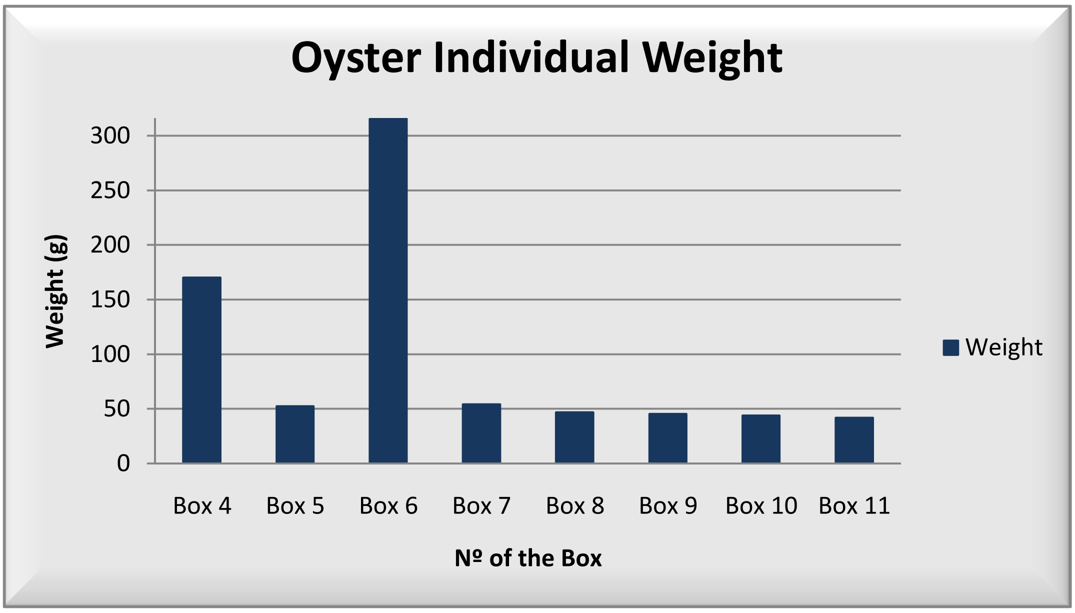

Figure 3.54 – Oyster individual weight

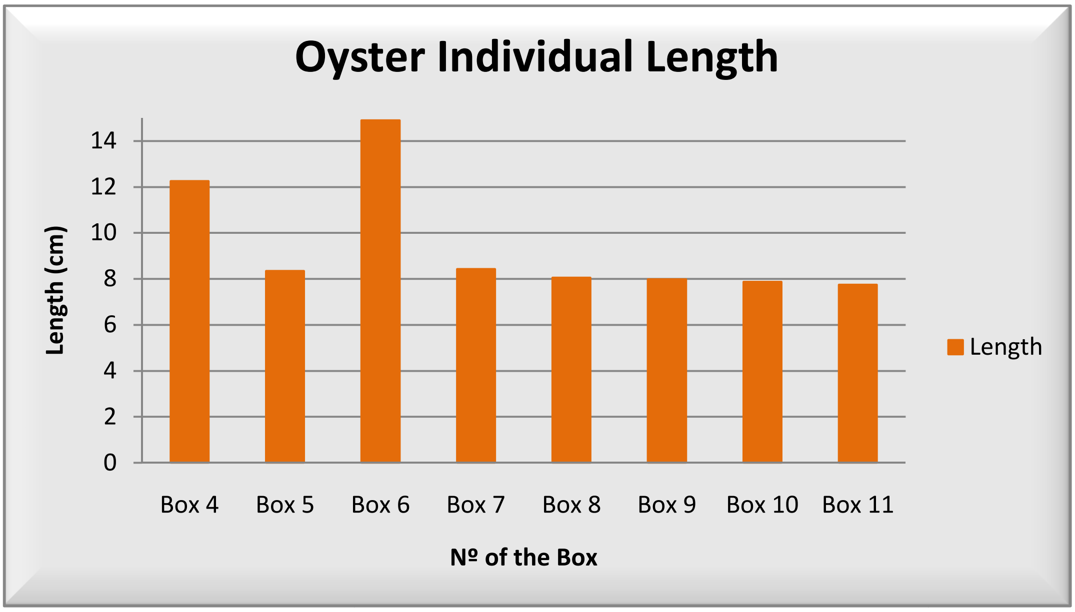

Figure 3.55 – Oyster individual length

Concerning to oyster production boxes 6, 7 and 8 still present the highest tonnes of oysters (Figure 3.56).

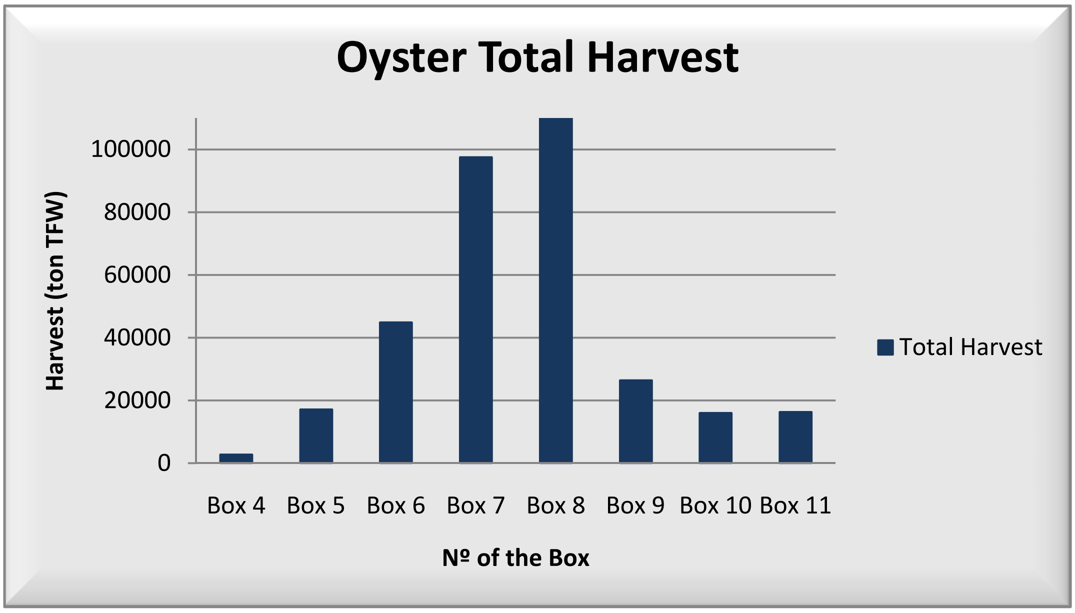

Figure 3.56 – Oyster total harvest

3.3. Scenario I

The increasing of 3^{0}C in water temperature decreases the oyster individual weight and length, as illustrate Figure 3.57 and Figure 3.58. In Figure 3.59, it can be seen the lost of tonnes of harvest mostly in boxes seven and eight.

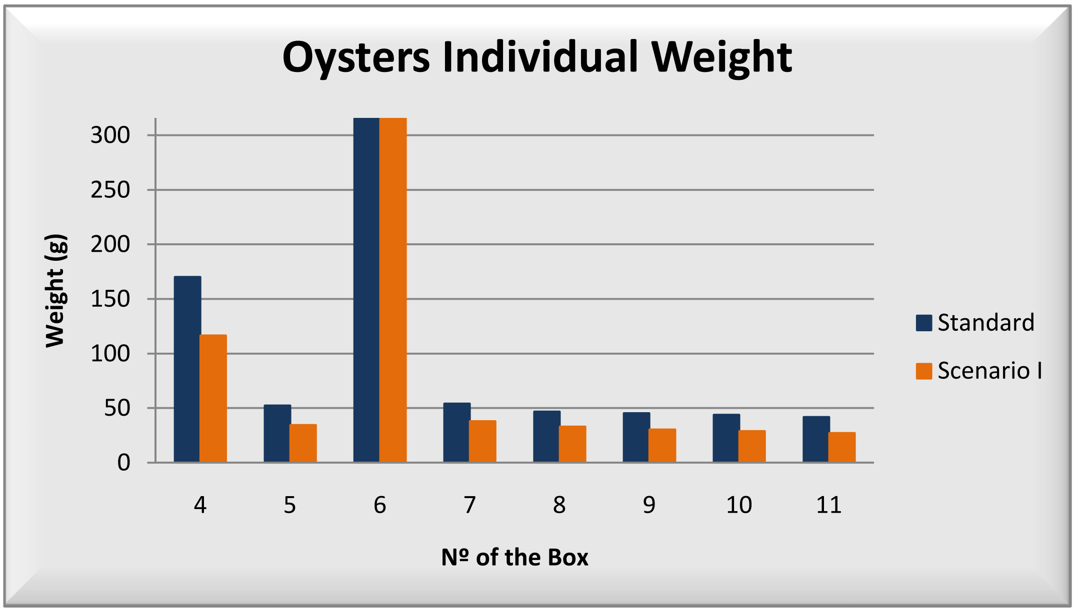

Figure 3.57 – Oyster individual weight: Scenario I

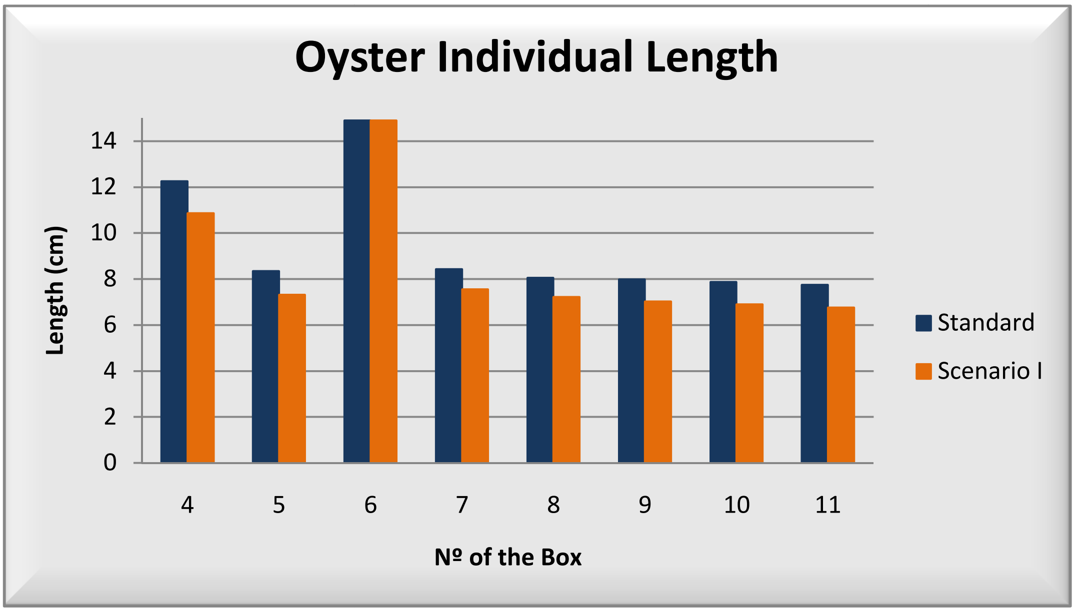

Figure 3.58 – Oyster individual length: Scenario I

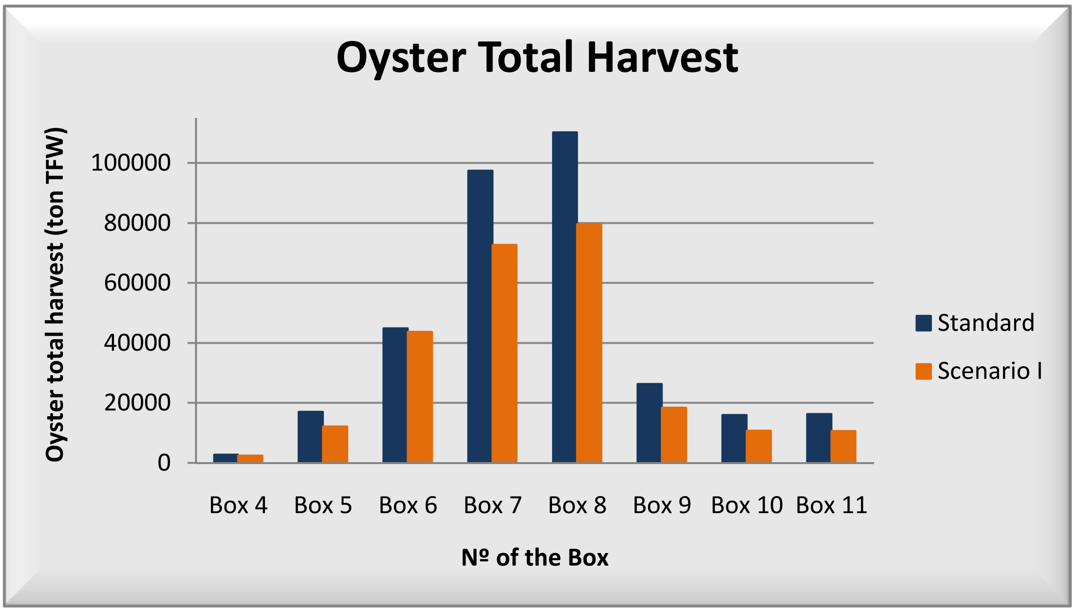

Figure 3.59 – Oyster total harvest: Scenario I

3.4. Scenario II

With modification of the first day seeding to one month before, the oyster individual weight (Figure 3.60) and length (Figure 3.61) decreases a little, but nothing significantly. Despite this fact, the oysters' total harvest increases more than one thousand of tonnes in some boxes (Figure 3.62).

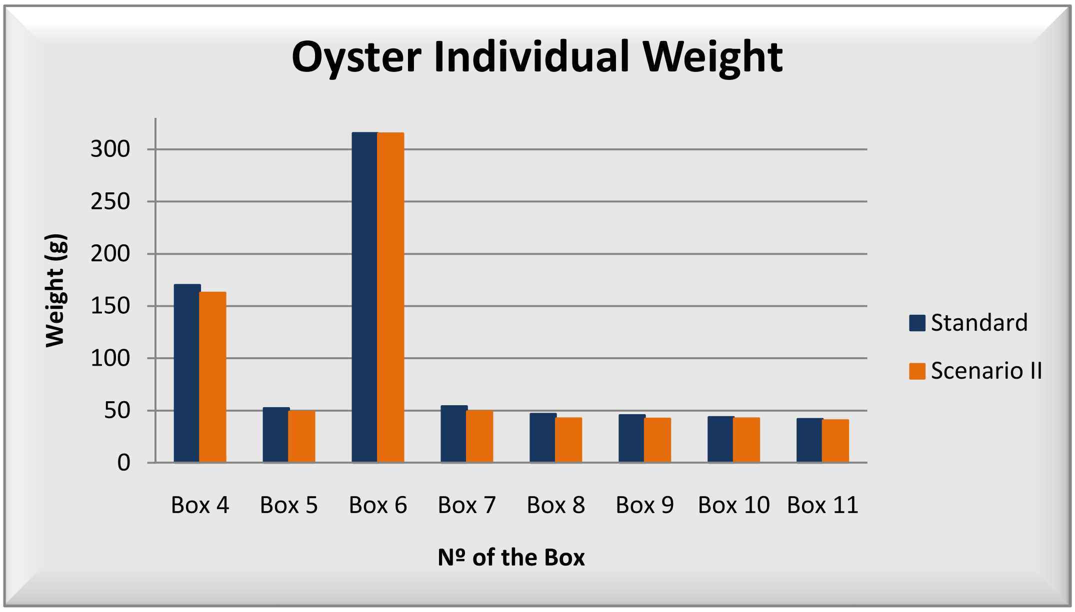

Figure 3.60 – Oyster individual weight: Scenario II

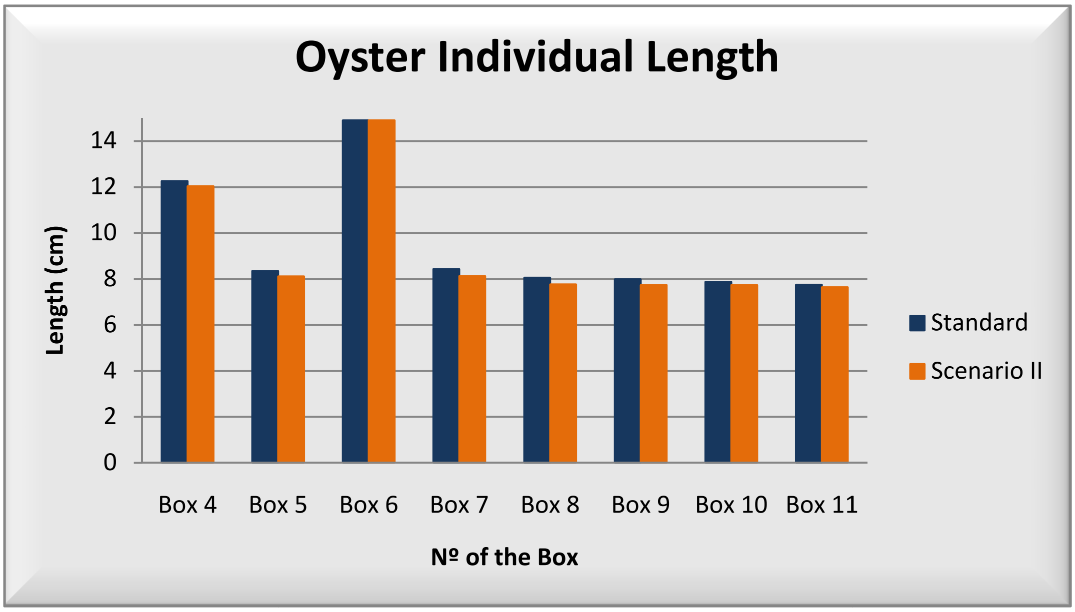

Figure 3.61 – Oyster individual length: Scenario II

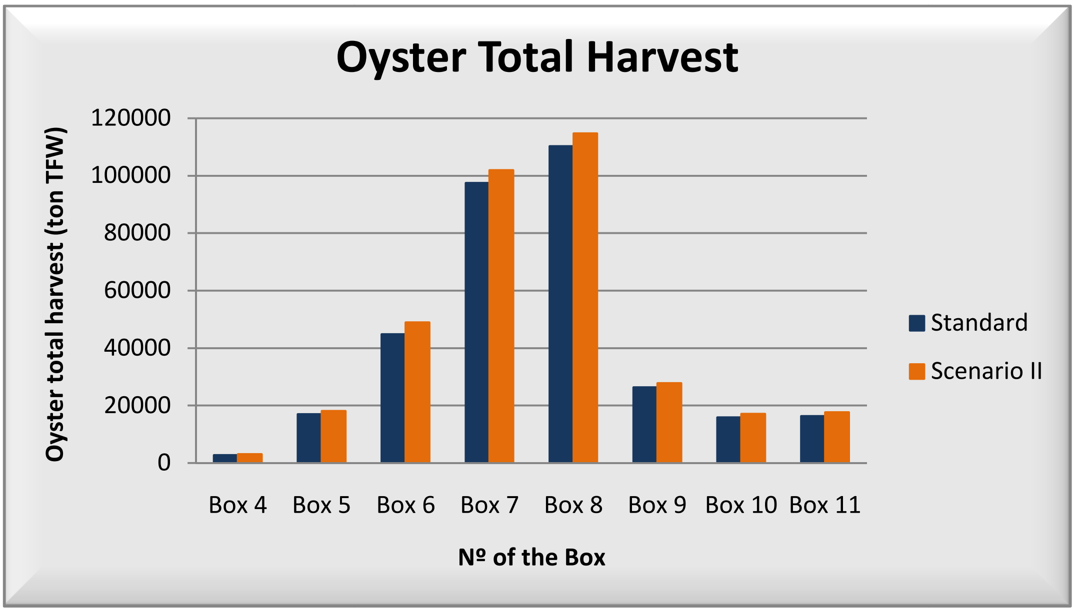

Figure 3.62 – Oyster total harvest: Scenario II

4. Conclusion

Shellfish aquaculture has been increasing since the last 20 years. For this reason, an ecological model was developed to simulate the oysters' growth in Tagus estuary. It was used data of 1980 and 1982 to calibrate and validate the model respectively, which shows a good correlation with the measured data.

Afterwards, it was simulated two different scenarios for testing the model in order to optimise the oysters' growth. On scenario I, the factor was the climate change and their consequence, so that it was increased 3^0C in water temperature, which resulted in decrease of individual oysters' weight and length as well as the oyster total harvest. As a result, if the water temperature increases, the production of oysters will be affected. On scenario II, it was considered the seeding period and it was tested the model starting the seeding on the 90 day instead of the 120 day. The results have shown that the oyster individual weight and length decreases slightly but the oysters' total harvest increase considerably.

Although the results show that the oysters can growth in the Tagus estuary, this model presents some limitations that should be taken into account in future developments, such as, the presence of zooplankton in the ecosystem, discharges, input of nutrients as well as social impacts that this type of culture could result in the region. In addition to those, should be made a monitoring campaign in order to improve the calibration and validation process.

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Annexes

Annex A – Data of zoobenthos from Esperança (1981, 1982)

Months	Length (mm)	Total Weight (g)
January	52	100
	56	197
	60	104
	63,5	108
	67	129
	69	166
	70	156
	70	160
	74	130
	78	149
	79	175
	79	206
	83	345
	83	156
	92	143
	112	305
February	51	92
	56	89
	60	110
	67	146
	68	146
	71	172
	73	229
	76	192
	87	197
	91	212
	107	208
March	-	-
April	54	74
	56	80
	62	121
	62	96
	70	162
	73	212
	76	185
	77	115
	81	181
	92	289

Annex A – Data of zoobenthos from Esperança (1981, 1982) (continuation)

Months	Length (mm)	Total Weight (g)
May	64	148
	69	140
	72	152
	72	110
	82	178
	83	184
	85	208
	85	270
	86	257
	91	229
June	57	98
	60	128
	68	178
	73	164
	75	150
	79	172
	80	215
	82	200
	88	230
	100	194
July	63	101
	70	148
	75	161
	75	208
	75	129
	78	195
	84	219
	90	238
	99	289
	106	282
August	52	128
	60	124
	62	141
	68	170
	73	168
	74	140
	85	326
	94	232
	104	272
	118	378

Annex A – Data of zoobenthos from Esperança (1981, 1982) (continuation)

Months	Length (mm)	Total Weight (g)
September	55	174
	56	106
	56	49
	56	82
	66	119
	68	123
	69	119
	74	103
	84	140
	84	134
October	53	111
	53	99
	60	129
	61	150
	62	91
	63	116
	71	80
	71	136
	77	74
	88	255
November	44	73
	61	76
	62	88
	65	109
	67	107
	74	88
	86	128
	90	244
	105	259
	114	262
December	53	106
	67	162
	71	134
	72	280
	79	170
	82	127
	84	215
	85	195
	89	170
	92	180

Annex B – Data of zoobenthos from Ramos (1982)

Station	Seeding Date	Initial Weight (g)	Final Weight (g)	Initial Length (mm)	Final Length (mm)	Mortality (%)
Ladeiro (2.9)	29.03.82	6	9,5	32,7	36,1	24
Ponta do Destroi (3.12)	29.01.82	11,2	17,3	36,2	42,9	11
Mouchão da Póvoa (3.15)	25.03.82	6,8	9,8	30,8	34,3	34
Banco dos Cavalos (3.13)	12.03.82	7,1	9,7	31,4	33,5	36