Università degli Studi di Milano - Bicocca

DEPARTEMENT EARTH AND ENVIRONMENTAL SCIENCES

Modelli di crescita di Orate in allevamenti marini.
Modeling of Gilthead sea bream growth in marine cages.

Laureando
Afef Boussadia
Matricola 788541

Relatore
Prof. Claudia Pasquero

A.A. 2016/2017

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CHAPTER 1

INTRODUCTION

1.1 Background and justification

World demand for seafood increased from 9.9 kg per capita in the 1960s to 19.7 kg in 2013, with preliminary estimates exceeding 20 kg per capita in 2015 (FAO, 2016). Therefore, the aquaculture provides opportunities to meet increased consumer demand for aquatic products while reducing the dependence on often over exploited wild stocks. World aquaculture production of fish accounted for 44.1 % of total production (including for non-food uses) from capture fisheries and aquaculture in 2014, up from 42.1 % in 2012 and 31.1 % in 2004 (FAO, 2016). The main challenges for the aquaculture sector include acceptability of aquaculture products related to impact on the environment, food quality and safety and all continents have shown a general trend of an increasing share of aquaculture production in total fish production. Gilthead sea bream *Sparus aurata* is an important aquaculture species in countries surrounding the Mediterranean Sea. In 2006, more than 90% of the gilthead sea bream aquaculture took place in just five of the twenty producing countries, with Greece being by far the leading producer (41 %), followed by Turkey (26 %), Spain (15 %), Italy (6 %) and Israel (3 %). This species is currently cultured in Many other Mediterranean countries, including Cyprus, France, Portugal, Croatia, Malta, Tunisia, Egypt, Albania, Bosnia, Algeria, Morocco and Slovenia. When analyzing the evolution of gilthead sea bream production, the FAO productions statistics recorded for gilthead bream are those from Italy in 1970 with 10mtn. Ten year later, in 1980, eight countries reported production outputs for a total of 775 mtn. Since then production grew rapidly and in 2006 production statistic include 20 countries. From 1986 to 1996 the average annual growth rate of gilthead production peaked at 44.6 % (Basurco et al.,2011).

However, for the following decade it decreases to 12.5% indicating a slower growth of the sector. The main reason for the slow development of gilthead sea bream industry was the initial difficulty in the production of a good quality of juveniles. However; the development of better hatchery techniques enabled the supply of the require juveniles. Production in 1990’s was rapid and inexpensive cage structure could be used in the many protected area along their coastline. The growth phase is primarily carried out in floating sea cages (Basurco et al.,2011) where fish performance and welfare are closely linked to environmental conditions within the sea cage.

The Mediterranean aquaculture industry has grown rapidly since its inception. In the southern coast of the Mediterranean and in northern Africa, Tunisia has 1300 km of coastline, where fisheries and aquaculture play a crucial socio-economic role. Over the last 25 years, aquaculture has expanded in Tunisia's coastal zone and is becoming an increasingly important industry, accounting for almost 3% of Tunisia's total fish production, which itself contributes nearly of 3% of gross domestic products (Abdou et al, 2016). On a Mediterranean scale, Tunisian fish farming is considered a small industry with a high potential for growth. It was ranked the 8th Mediterranean reared fish producer in 2013, and its production represents almost 1% of total aquaculture production in the Mediterranean Sea (FAO, 2016).

The development of sustainable aquaculture in Tunisia requires, first, a common understanding of sustainability concepts, especially with respect to marine aquaculture. Controlling fish growth is one of the essential keys of profitability in aquaculture industry and managing such on-growing systems requires a growth model to describe the response of the fish to their environment. Fish growth models may help understanding the influence of environmental, physiological and husbandry factors on fish production, providing crucial information to maximize the growth rate of cultivated species (Serpa et al., 2013). Studies over the past 30 years produced a considerable volume of growth data, especially in marine cages, resulting in several fish growth models. Adequate growth models are essential for rational management, as they guide the feeding and handling of fish from the instant of stocking to the instant of harvesting. Seginer, 2016 attempts to critically review the available information from an aquacultural management point of view, selecting simple sub-models which preserve the essentials of the various processes. It seems that for the practical range of application for gilthead sea bream, growth is dependent on body size and dependent on both temperature and feed ration. A representative growth model with these features calibrated with the available data, is proposed.

The fish growth is influenced by different factors and it’s essential to consider that in sea cage farming, fish are exposed to seasonal variations of water temperature, and these variations can differ from one location to another. The economic impact of improving growth rate in sea cage farming system depends on temperature, knowing that this factor will define the growth rate for every stage of life of the fish, Mayer et al. (2008,2009,2012) studied various growth models for the gilthead sea bream considering the variability of water temperature.

One of the key findings was that the best models, including the Thermal growth coefficient (TGC) model, were those that considered the accumulated effective temperature as an independent variable.

The model is a particular version of the von Bertalanffy equation that incorporates a cumulative water temperature, which allows an estimation of fish growth in several temperature conditions, constituting an interesting tool for aquaculture management.

1.2 Objectives of the thesis

The development of a suitable growth prediction model, adjusted to the real conditions of intensive production, could be an important tool for reducing the production costs by optimizing the daily food ration, the organization of management operations and the production plan.

The main objective of the thesis was an initiation to establish an accurate and simple prediction model for Gilthead sea bream, growing in marine cages in the Mediterranean Sea, taking into account previous models cited in the bibliography and other regression models developed from data obtained in a marine fish farm, under real production conditions.

The specific objectives were:

- assessment of annual fluctuations of fish weight, weight gain, specific growth rate, specific feeding rate depending on temperature and to compare the growth and the functional traits at successive years.
- evaluation of the relationships between the different functional rate related to growth and to fish performance.
- testing two predictable growth models based on temperature, in order to evaluate the accuracy of data of growth under real production conditions system and to compare real growth with the predicted growth.

1.3 Set-up of the research

In this research, the experimentation was conducted at an offshore fish farm, located at the central coastal zone of Tunisia, at three miles from the land based (habor).

The fish farm was established since 2010 and the data was collected from 2010 till 2016, in order to assess the growth and to evaluate the management strategy. The data collected has been dedicated for the present study, in order to implement a model predicting the growth and adapted to environmental conditions. In total, 21 cages, constituting 21 different lots of Gilthead sea bream (*Sparus aurata*) were selected and carried out, from the stage of pre-growing, to the on-growing and harvesting period at different weight sizes.

1.4 Thesis outline

The thesis comprises five distinct chapters, each covering a specific topic. In Chapter 2, a literature review is given about the importance of the aquaculture in the Mediterranean Sea and its specification. Chapter 3 deals with the assessment of the growth of gilthead sea bream (*Sparus aurata*) farmed in marine cages in Tunisia under real production conditions and describes the factors influencing the functional traits and the growth under real production conditions. Chapter 4 gives a concise assessment of predictable growth model, Thermal growth model for gilthead sea bream farmed in marine cages under real production conditions. Finally, a general conclusion that summarises all findings and provides perspectives for future research is presented in Chapter 5.

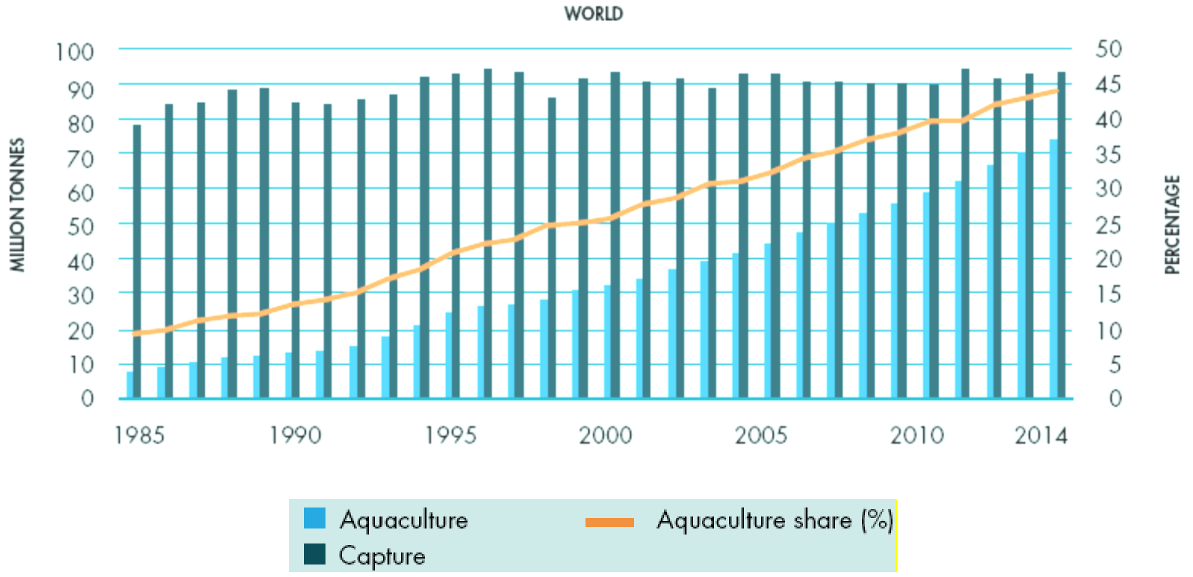
CHAPTER 2

AQUACULTURE IN THE MEDITERRANEAN SEA: CURRENT APPROACH OF MODELLING CONCEPTS AND FUTURE CHALLENGES OF THE FISH FARMING

2.1 Aquaculture sector, general status and trends

Global aquaculture has grown dramatically over the past 50 years to around 52.5 million tonnes (68.3 million including aquatic plants) in 2008 and accounting for around 50 per cent of the world's fish food supply, while capture fishery production remains relatively static since the late 1980s (Bostock and al, 2010).

World aquaculture production of fish accounted for 44.1 percent of total production (including for non-food uses) from capture fisheries and aquaculture in 2014, up from 42.1 percent in 2012 and 31.1 percent in 2004 (Figure 2.1).



Source: FAO, 2016

Figure 2.1: Share of aquaculture in total production of aquatic animals

All continents have shown a general trend of an increasing share of aquaculture production in total fish production.

In 2014, fish harvested from aquaculture amounted to 73.8 million tonnes, consisting of 49.8 million tonnes of finfish, 16.1 million tonnes of molluscs, 6.9 million tonnes of crustaceans and 7.3 million tonnes of other aquatic animals including frogs (FAO, 2016).

In the decade 2005–2014, fish culture production grew at 5.8 percent annually, down from the 7.2 percent achieved in the previous decade (1995–2004).

Inland finfish aquaculture, the most common type of aquaculture operation in the world, accounted for 65 percent of the increase in fish production at the period 2005–2014. Inland finfish culture in earthen ponds is by far the largest contributor from aquaculture to food security and nutrition in the developing world, although cage culture of finfish is increasingly being introduced to places where conditions allow (FAO, 2016).

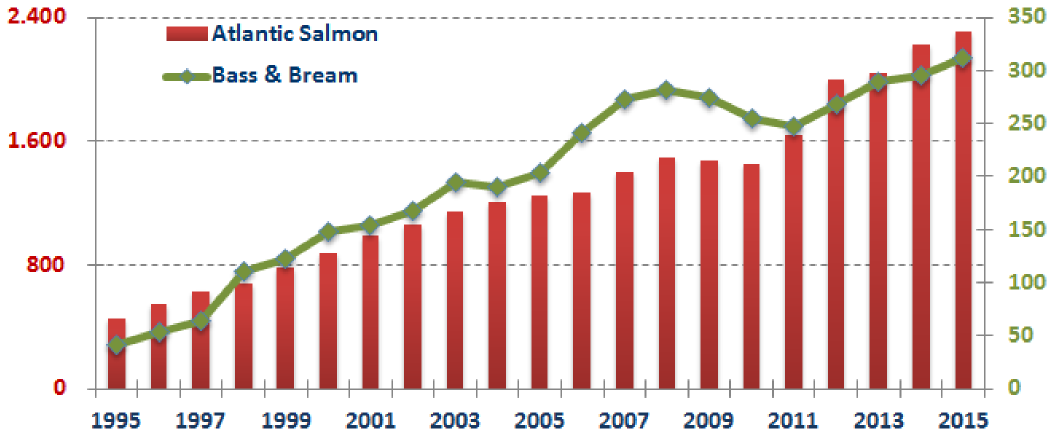
2.2 Aquaculture in the Mediterranean Sea

2.2.1 Species produced in the Mediterranean Sea

Excluding aquatic plants, 310 species were recorded by FAO as cultured in 2008.

By 2014, a total of 580 species and/or species groups farmed around the world, including those once farmed in the past. These species items include 362 finfishes, 104 molluscs, 62 crustaceans, 6 frogs and reptiles, 9 aquatic invertebrates, and 37 aquatic plants. (FAO, 2016)

Freshwater fish production is dominated by various species of carp, although tilapia and later pangasius catfish have become more significant. Coastal aquaculture primarily comprises shrimp, oyster, scallop and mussels, with Atlantic salmon as the leading intensively farmed, marine fish. Marine fish farming accounts for just 3% of global aquaculture production in volume, but it contributes 8% of its total value. The largest sector of marine fish farming is the long established culture of Atlantic salmon, while bass and bream culture is the second largest sector globally with a total production over than 300 thousand tons for 2015 (Figure 2.2).



Source: FEAP 2016

Figure 2.2: World production of marine fish farming, from 1995 to 2015 (Thousand tonnes)

2.2.2 Importance and perspective of aquaculture in the Mediterranean Sea

The Mediterranean coast is about 46 000 km long, with some 15 000 km suitable for aquaculture production on the northern shore (from Spain to Turkey) and 4 000 km on the southern shore. Today, the Mediterranean Sea plays a central role. The marine resources and ecosystems of this region, however, have come under increasing pressure in recent decades, driven by demographic and economic growth as well as by diversification and intensification of marine and maritime activities e.g. pollution, alien species, illegal fishing and overfishing all pose threats. Yet, fish farming in individual countries grew very differently, depending upon local conditions.

Mediterranean fish farming is a multi-species cultivation. The major cultivated species are seabass and seabream and their farming accounts for approximately 95% of total production. Their share in total production volumes is decreasing as new species (i.e dentex, meager, red porgy) are developed.

The major markets for seabass and seabream are located in southern Europe, where both species belong to fishing and culinary traditions. First Turkey, and then Greece and Spain, are the most well established and large-scale markets. From 2007 to 2015, the production of seabass soared from 41.900 tonnes to 77.000 tonnes in Turkey, and from 10.480 tonnes to 21.324 tonnes in Spain.

Over the same period, the production seabream increased from 33,500 to 48,000 tonnes in Turkey and decreased from 79,000 tonnes to 65.000 tonnes in Greece and from 22.320 tonnes to 16.231 tonnes in Spain (FEAP, 2016).

Total European Mediterranean countries including Turkey, produced 148.367 tons of sea bass and 146.467 tons of sea bream in 2014 (FEAP, 2015).

Greece, Turkey and Spain are the main countries producers of seabream and seabass and maintain a share of approximately 80% of the world production. The remaining 20% is produced in Italy, France, Portugal, Croatia, Cyprus and countries of North Africa and Middle East.

2.3 Tunisian Aquaculture fish farm: Background and importance of the activity

Tunisia maintains a Mediterranean coastline of 1,350 km with a national maritime domain of 80,000 km^2 and 105.200 ha of lagoons. However, while Tunisia has long been a country of sailors and fishing, aquaculture remains a niche industry, accounting for 12% of total fishery production.

The beginning of Tunisia's modern aquaculture industry began in the 1960s with a government-established shellfish farm. The first private hatchery of Sea Bass, *Dicentrarchus labrax* and Sea Bream, *Sparus aurata* was later established in the 1980s. Fattening of Bluefin Tuna, *Thunnus thynnus* was launched in 2003, and last ten years have been marked by the expansion of floating and submersible cages for Sea Bass and Sea Bream. Tunisia's aquaculture production rose from 140 MT in 1987 to 15.200 MT in 2016 (Gain, 2017). The leading products in terms of quantity and value are sea bass and sea bream, which represent 87 percent from the total production (Figure 2.3).

Table 2.1: Aquaculture production in Tunisia, 2007-2016

(Millions Tons)

	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shellfish	200	129	158	167	166	115	113	162	171	183
Bluefin Tuna Fattening	519	600	380	373	350	841	380	480	505	520
***Other Marine Fish** (e.g., Sea Bass; Sea Bream)*	1.583	1.901	2.804	4.000	5.837	7.272	10.500	9.994	10.897	13.237
Inland fish	1.114	1.114	1.125	1.176	919	969	997	1.034	1.080	1.260
TOTAL	**3.416**	**4.658**	**4.467**	**5.716**	**7.272**	**8.736**	**11.990**	**11.670**	**12.653**	**15.200**
		+36%	-4%	+28%	+27%	+20%	+37%	-3%	+8%	+20%

(Gain, 2017)

The reared species with the highest economic value are European seabass, *Dicentrarchus labrax* and gilthead seabream, *Sparus aurata*, for which market prices per kg range from 9 to 12 TND (equivalent to 3.66–4.88€) and 8–10 TND (3.25–4.07€). In light of current social, economic and environmental contexts, it is necessary for aquaculture production systems in Tunisia to develop sustainably. On a Mediterranean scale, Tunisian fish farming is considered a small industry with a high potential for growth. It was ranked the 8th Mediterranean reared fish producer in 2013, and its production represents almost 1% of total aquaculture production in the Mediterranean Sea (FAO, 2016).

There are 25 offshore aquaculture farms in Tunisia's exclusive economic zone (EEZ), located on the country's eastern side (Abdou et al., 2017).

Production varies considerably among farms: Large farms produce 2600 tons per year while small farms produce approximately 600 tons per year. Difference in production among farms is a direct result of the number of cages and the aqua cultural techniques they adopt.

From 2013 to 2015, the major cultivated species in offshore fish farm is sea bream, with a share of 80 per cent of the total production volume per farm, and only 20 per cent for sea bass. The disproportion of production between the two species is mainly related to the technical and disease difficulties affecting mostly sea bass than sea bream.

2.4 Production system of gilthead sea bream

Domestication of gilthead sea bream (*Sparus aurata)* started at the 1970s and developed to a large-scale industry in the Mediterranean area.

The production system is of several type and using a variety of technologies, including inshore and offshore cages, onshore extensive earthen ponds and lagoon sites, intensive land-based concrete tanks with a flow through water supply and even super intensive recirculating system. The production systems of sea bream and sea bass in the Mediterranean are dominated by cage culture. The number of farms using land based facilities is much smaller, and mainly used for the pre-growing stage with a few grow out facilities (Basurco et al, 2011).

This paragraph includes a description of a wide range of topics related to the production aspects of sea bream, starting with technical aspects of the hatchery and nursery stages for fingerlings production. In the following sections, a technical description of production system is given.

2.4.1 Hatchery and nursery for fingerlings production

Hatcheries for Sparidae family include the standard facilities for plankton production, larval rearing and weaning – nursery. Gilthead sea bream eggs are produced in land-based hatcheries from selected broodstock of various age groups, from 1-year-old males to 10-year-old females. The broodstock are normally kept in tanks (10–20 m^3) at a density of 4–8 kg m^{-1}. In order to ensure a good fertilization rate, as females are batch spawners that can lay about 20,000–30,000 egg kg^{-3} for a period of 3–4 months, the male to female ratio is normally kept at 3:1 (Basurco et al, 2011).

Larval rearing is one of the most critical stages for successful propagation of the specie. Therefore, the development of appropriate tools for this stage is essential. Larvae of Sparidae family are very small (total length of approximately 3-4 mm) at first feeding and therefore are sensitive to the rearing environment and to food quality (Pavlidis and Mylones, 2011).

Larval survival and growth are related to egg size and hatching time that can be measured as continuous traits and spawning substrate (Winemiller and Rose 1992; Franco et al., 2008; Villeger et al., 2017).

There are two principal systems of gilthead seabream larval rearing. The main classifications are based on the rearing density (intensive, extensive). In intensives hatcheries, larvae are reared at high densities under control conditions and success is highly depended on the level of knowledge of the larvae specific biological needs. Feeding is based on the food chain of reared planktonic organism.

As growth and survival depend to a great extent on food availability and environmental conditions during rearing, understanding the rate of food consumption and assimilation efficiency is a determining factor in establishing successful methodologies of larval rearing for aquaculture enterprises. Furthermore, the basic infrastructures that are essential for any kind of inland aquaculture operation (system of seawater distribution, electric supply, air and oxygen networks) are required.

The use of live preys and phytoplankton is a common characteristic in larval rearing methods. Special facilities in the hatcheries are requested for this purpose, as phytoplankton culture, zooplankton culture, rotifers and artemia.

For rearing marine fish larvae, algae are used directly in the larval tanks. This technique is nowadays a normal procedure in marine larviculture, given that it has been widely reported to improve fish larval growth, survival and feed ingestion (Makridis., 2000; Reitan et al., 1997; Rainuzzo et al., 1997; Conceicao et al., 2010).

Since the 1970s, the rotifers and more specifically *Brachionus plicatilis* constitute an essential part of the feeding during the larval stages of marine fish and crustaceans (Lubzens and Zmora 2003; Conceicao et al., 2010). Its body size (between 70 and 350 mm depending on the strain and age) makes this organism an appropriate prey to start feeding after the resorption of vitelline reserves of many species. In fact, Brachionus is widely used as food during a period of days or weeks depending on the reared species, being replaced afterwards by a larger prey species, usually *Artemia nauplii* (Conceicao et al., 2010). An important limitation of Artemia spp. Enrichment as a tool to study larval nutritional quantitative and qualitative requirements is the notorious lack of consistency in this procedure, as considerable variability has been reported in the essential fatty acid content after Artemia spp. enrichment despite attempts to standardize protocols (Merchie 1996; Conceicao et al., 2010). The weaning onto commercial feeds usually starts at the last stages of the larval period, after several weeks of live prey feeding.

However, mixed feeding on live prey plus inert diets during earlier larval stages has been tested since the 1980s. These co-feeding assays have been performed with different aims: to know to what degree larvae accept, digest and tolerate inert diets in order to advance the complete replacement of live prey.

In general, different studies show that fish larvae of different species grow very well in co-feeding when the live prey substitution level is not excessive (Conceicao et al., 2010).

2.4.2 Pre-on growing

Before being transferred to on-growing facilities, the juveniles usually remain in the hatchery until they reach a weight of 2-5 g. In case that on-growing is performed in open sea conditions, then the pre-growing period can be extended until individuals to reach a weight of 10-30 g, depending on the management strategy of the farm. During this period several producers are commonly applied including grading, vaccination and quality control.

Grading is performed as in most of the cases reared populations present an uneven distribution of size within the same batch. This can result in husbandry difficulties and generate cannibalism phenomena. Size uniformity is therefore important.

Grading is performed with aid of sorters usually plastic or metal consisting of bars with intervals between 4 and 6 mm while automatic grader has been developed in experimental scale (Pavlidis and Mylonas., 2011). Malformations during the hatchery process are variable and can result in significant economic losses.

Usually include skeletal deformities in snout, opercula and the absence of swim-bladder. Selection of malformed individuals usually takes place in the hatchery, when fish are more than 0.5 g in weight and it is a manual process (Pavlidis and Mylonas., 2011).

The major concern of any producer is the quality of the juveniles received from the hatchery as this will establish large part of the performance of the production cycle. In addition to the removal of the deformed individuals, typical divergence in size should be not more than 20-22% of the average weight of the batch.

Fish transportation from hatcheries to on-growing facilities represents the end of the hatchery phase and the beginning of the on-growing. The food requirements of the larvae change according to size and vary under the influence of several parameters such as behavior (Kentouri., 1985) and environment. Therefore, successful methodologies when applied on a commercial scale, require experienced practice, since larval consumption must be monitored continuously in order to adjust food availability according to demand.

Fluctuations in feeding requirements of fish population when they are based on pre-defined feeding tables, can be a constraint. Hence, it is important to develop tools that adjust the delivered amount of food to the changing needs of the fish (Papandroulakis et al., 2000). Fish transportation from hatcheries to on-growing facilities represents the end of the hatchery phase and the beginning of the on-growing.

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2.4.3 On-growing cage culture and production management

Gilthead sea bream production in the Mediterranean is performed in floating cages. Cage technologies include a variety of specification, and the appropriate choice will depend of number of specific requirements like site location, species, ect…

Stocking density can reach an average of 30-40 kg/m^{-3}, although generally is in the range of 15-20 kg/m^{-3}, in accordance to the water current conditions of the farm's site location (Pavlidis and Mylonas., 2011).

Fish stocks are fed in the cages either by hand, particularly for a smaller fish and feed pellets between 1.3 and 3 mm of diameter or using air or water pressure pumps faster and more efficient for feed pellets between 4.5 and 6 mm of diameter.

Routine work in this type of farms include daily observations of fish behaviour to detect outbreaks diseases, removal of dead individuals, general surveillance, and removal and replacement of damaged cage components, including net bags periodical substitutions. The nets are performed by inserting and hanging the clean net over the old, which is then liberated and towelled from the service boat.

When fish reach market size, harvesting is carried out with purse seine net inside the cage, fish being scarified on-board with mixture of ice and seawater. The culture period varies with location and water temperature, but usually it takes between 18 and 24 months for a specimen to reach 400 g from hatched larvae. Commercial size can vary from 250 g to more than 1.5 kg.

Management and feeding systems have been developed for the on-growing phase of the aquaculture production process.

These systems based on models (Cho and Bureau., 1998), on feeding tables (Arnason et al., 1995; Papandroulakis et al., 2000) or on computer-controlled systems (Kadri and Blyth, 1997; Papandroulakis et al., 2000) are used in commercial scale.

By predicting the effects of environmental (temperature), physiological (assimilation and excretion rates) and husbandry factors (feeding rates) on fish performance, growth models may be of considerable help for the aquaculture industry, to maximize the growth rates and efficiencies of cultivated fish (Alunno-Bruscia et al., 2009; van der Veer et al., 2009; Serpa et al., 2013).

2.5 Theory basis of fish growth modelling

2.5.1 Population dynamic growth and the von Bertalanffy model

The literature refers to many growth models among which the natural populations hold a large part. These models allow us to know the evolution over time of the biomass and intervene in the management of the stocks. Most often, they are inspired by Bertalanffy's (1938).

The Von Bertalanffy equation is probably the most-studied and applied equation for describing and predicting growth of ectotherms, organisms which internal physiological sources of heat are of relatively small or negligible importance in controlling body temperature. The body temperatures of aquatic ectotherms are usually very close to those of the water (Ricker 1979; Rosa et al., 1997; Hernandez-Llamas and Ratkowsky 2004; De Graaf and Prein 2005; Jauralde et al., 2013). Von Bertalanffy (1957) in equation (2.1) expressed the rate of growth G of an organism as:

$$G \equiv \frac{dM}{dt} = \eta M^{\alpha} - \kappa M^{\beta} \tag{2.1}$$

where α and β (dimensionless), η (in g $[BM]/fish)^{1-\alpha}/day$), and κ (in g$[BM]/fish)^{1-\beta}/day$), are allometric constants.

The von Bertalanffy equation was developed for natural conditions and long-life spans. The implicit time step is usually a year and the environmental conditions, in particular temperature and food availability, are assumed to be periodic (annually) and their average effect implicit in the coefficients η and κ.

In equation. (2.1) the change in body weight [mass] is the difference between processes of building up [anabolism] and breaking down [catabolism]" (von Bertalanffy., 1957). The best fit for most fish was found by equation (2.2), where if G is equal to zero, we can estimate M.

$$G = \eta M^{2/3} - \kappa M \qquad M_\infty = (\eta/\kappa)^3 \tag{2.2}$$

2.5.2 General growth functions and Empirical models

In general, the development of a fish (or an organism) is a function of its own state (size, condition), S, and the state of its environment (temperature, food, water quality), E, namely, where t (normally in days) is time, and G is the growth rate of S:

$$\frac{dS}{dt} = G\{S, E\} \tag{2.3}$$

S, E and G are vectors which may be expressed at different levels of detail. In models for aquaculture the state is often represented by just M, the fresh body mass (BM) of a single fish (g[BM]/fish), while the environment vector often consists of just temperature, T (°C), and feed ration F (g[feed]/(g[BM]day)).

Depending on the limiting environmental factors, the growth function G may be made to respond, in addition to T and F, to feed composition (Lupatsch et al., 2003).

Assuming that feed composition and environmental quality are adequate (not limiting growth), most of the sea bream studies involve short term growth (1–2 years) under aquaculture conditions, where fish are confined and supplied with artificial feed.

The commonly considered arguments of the growth function or predictors of growth, namely M, T and F. Hence Eq. (2.3) becomes in this case:

$$\frac{dM}{dt} = G\{F, T, M\} \tag{2.4}$$

All growth models based on Eq. (2.4), are some mix of biological concepts and empirical relationships. They may be classified in several ways. For example, Dumas et al., (2010) identified three conceptual sources: The Malthus equation of exponential growth, as a first concept, the concept of Growing Degree-Days (Bonhomme., 2000).

According to Seginer (2016) it is convenient to classify the models into ‘two-term’ and ‘single-term’ models, where the latter is a simplification of the former.

The ‘two-term’ models are either mass- or energy-balance models where the rate of growth is formulated as the difference between anabolism, A, and catabolism, C.

The ‘single-term’ models are empirical simplifications of the two-term’ models, where catabolism is taken implicitly into account.

The single-term models are often used in practice and commonly simplified, as the following equation (2.5) (Corey et al., 1983; Stauffer, 1973; Seginer, 2016).

$$G = G_r . g_f\{F, T, M\} . g_T \ \{T\}. g_M\{M\} \tag{2.5}$$

Where G_r is growth at reference conditions and g_f, g_T, and g_M are non-dimensional response functions or correction factors to feed, temperature and fish size, which produces good empirical fits over limited domains.

2.5.3 Bioenergetic models and DEB

The basic traditional concept of bioenergetic models of individual animals describe energy acquisition from feeding, and its partitioning among processes such as growth, reproduction, respiration, excretion and activity. These processes are commonly defined operationally; for example, growth and reproduction may be measured directly and converted to energy units, activity may be defined through changes in respiration rate, and other terms may relate to data on heat balance or mechanical work done. Consequently, the traditional bioenergetics models are powerful data synthesis tools with a strong empirical foundation (Nisbat et al, 2012). As example of the fundamental bioenergetic models, Scope For Growth (SFG) and Dynamic Energy Budget (DEB) are presented in the following section.

2.5.3.1. Scope For Growth (SFG)

Scope for growth (SFG) define the energy status of an animal, which can range from maximum positive values under optimal conditions, declining to negatives values when animal is severely stressed and utilizing body reserves. Growth integrates major physiological responses, specifically the balance between process of energy acquisition (feeding and digestion) and energy expenditure (metabolism and excretion), as demonstrated by Widdows and Staff, (2006) in equation (2.6).

$$C - F = A = R + E + P \quad (2.6)$$

Where, C: total consumption of food energy, F: faecal energy loss, A: absorbed food energy, R: respiratory energy, E: energy lost as excreta and P: energy for growth or reproduction (scope for growth).

Therefore, if this balance is positive, the organism has energy available for growth and reproduction that is manifest as an increase in body weight. In contrast, a negative balance will result in a decrease in body weight, as a consequence of the utilization of reserves.

SFG was primarily developed to assess the whole -animal response to sublethal stress induced by pollutant. It was a successful concept used for mussels (Mytilus edulis or similar indigenous species) to analyse chemical contaminants in mussel tissues (Widdows and Staff, 2006).

But it's also an approach based on the measurement of the energetic balance of a "standard" organism, to apply allometric curves to extrapolate the measurement to other animal sizes and to simulate the growth (Filgueira et al., 2011).

2.5.3.2. Dynamic energy budget (DEB)

One of the most encompassing theories of dynamic energy budgets is the DEB theory developed by Bas Kooijman in the 1980s (Kooijman, 2000). The approach of DEB theory (Kooijman, 1993; Kooijman, 2010; Nisbet et al., 2000) starts from a set of well-defined assumptions and provides a characterization of the complete life cycle (embryo, juvenile and adult) of an animal through a 'standard' model with 12 parameters. (DEB) model of an individual organism describes the rates at which the organism assimilates and utilizes energy for maintenance, growth and reproduction, as a function of the state of the organism and of its environment (Nisbet et al., 2000; Kooijman, 2001; Meer, 2006).

The state of the organism can be characterized by, for example, age, size and amount of reserves, and the environment by e.g. food density and temperature. It predicts both interspecific and intraspecific variation in the many energy and mass fluxes in any biologically relevant environment (Nisbet et al., 2012).

Starting from an equation describing energy or mass balance requirements (Eq.2.7), where, the 'input' is the feeding rate (C); the 'outputs' include egestion (F) and excretion rates (U), growth rate (G) and total metabolic rate. Each term may in turn be decomposed into component terms.

Thus, it may be useful to distinguish the contributions to growth rate from somatic growth, gonad production and storage of fats and lipids.

Total metabolic rate can be decomposed into specific dynamic action (SDA; represented in equations by *S*) and maintenance, with the latter commonly described as the product of standard (or basal) maintenance (*M*) and a dimensionless factor called 'activity' (*A*). Note that maintenance here has a different meaning from its use in DEB theory. Ignoring the different components of growth, the energy balance equation then takes the form (Nisbet et al., 2012):

$$C = G + MA + S + F + U \tag{2.7}$$

To define growth rate and total metabolic rates, the different components of an energy budget are often expressed in energy per day per unit of (wet) weight. The (wet) weight of an individual W_w is defined as follow:

$$W_w = W_V + W_E + W_R = d_V V + \frac{w_E}{\mu_E}(E - E_R) \tag{2.8}$$

where W_V is the structural weight (g), W_E is the reserve weight, W_R is the weight of the reproduction buffer, d_V is the density of the structural volume, and wE and μE are the molar weight and the chemical potential of reserve, respectively.
For food consumption, the standard DEB model considers one type of food with density denoted by *X* and assumes constant assimilation efficiency K_X ($0< K_X <1$). Food consumption rate, C, is expressed as follows (Eq.2.9)

$$C = \frac{1}{W_w} p_X = \frac{1}{W_w K_X} p_A \tag{2.9}$$

where p_X is the ingestion rate and $p_A = K_X\, p_X$ is the assimilation rate.
The growth (G), in DEB model refers only to increase in structure. In traditional bioenergetic models, growth (*G*) is defined as the amount of energy fixed in new tissues per day and per unit of weight. In DEB terms, it thus includes the energy fixed in reserve, in structure, and (for adults) in the reproduction buffer (Eq. 2.10):

$$G = \frac{1}{W_w}(p_A - (1 - K_G)p_G - p_D) \tag{2.10}$$

In this equation, $(1\text{-}K_G)\ p_G$ represents the overheads of growth (of structure) and $p_D=p_S+p_J+(1\text{-}K_G)\ p_R$ represents the ‘dissipation’ terms, which encompass all processes not associated with the production of new reserve and new structure. The parameter $K_G=\mu_V d_V/(w_V[E_G])$ $(0< K_G <1)$ is the fraction of energy for growth that is fixed into structure.

The Egestion (F), this term also has a unique link with DEB processes:

$$F = \frac{1}{W_w} K_P p_X = \frac{1}{W_w} \frac{K_P}{K_X} p_A \qquad (2.11)$$

with K_P the fraction of the ingestion rate transformed into feces ($K_P <1– K_x$).

The excretion (U) is subtracted from the digestible energy to obtain the metabolizable energy that fuels growth and maintenance (Brett and Groves, 1979; Nisbat et al., 2012). Excretion is thus primarily associated with assimilation. However, excretion of previously assimilated nitrogen (e.g. during protein turnover) is regarded as one of the components underpinning trophic isotopic enrichment in animals (Ponsard and Averbuch, 1999; Nisbat et al., 2012). As with respiration, the excretion term in the standard DEB model is not a single process but can be expressed as a sum of the contributions from the three basic transformations assimilation, growth and dissipation (Eq.2.12):

$$U = \frac{1}{W_w} \mu_N (J_{NA} + J_{NG} + J_{ND}) \qquad (2.12)$$

with μ_N (JCmol^{-1}) denoting the chemical potential of the nitrogen waste produced and $\dot{J}_{NA}$, $\dot{J}_{NG}$ and $\dot{J}_{ND}$ (Cmolday^{-1}) denoting the mass fluxes of nitrogen waste produced during assimilation, growth and dissipation, respectively. Each component of the nitrogen waste flux is fully determined by the mass balance equations, and so does not require extra parameters.

The specific dynamic action (SDA; S) is identified by Kooijman with the ‘heat increment of feeding’ and included it in the overheads of assimilation (Kooijman, 2010). In this case, if there is no fermentation, SDA is equal to the overheads of assimilation minus egestion minus excretion due to assimilation (Eq.2.13):

$$S = \frac{1}{W_w} [(1 - K_x) p_X - K_P p_X - \mu_N J_{NA}] \qquad (2.13)$$

Standard metabolism and activity rate of an animal is defined as the metabolism (M) of an inactive fish that is not digesting food. If we define activity (A) as the amount of energy spent on movement necessary to survive (e.g. to respire, to eat), then we can link the product MA to the following combination of DEB processes: overheads of growth + somatic maintenance + maturity maintenance + development or the overheads of reproduction – excretion during growth and dissipation processes (Eq.2.14):

$$M \times A = \frac{1}{W_w}[(1 - K_G)p_G + p_D - \mu_N J_{NG} - \mu_N J_{ND}] \tag{2.14}$$

It should be noted that determining the elemental composition of reserve and structure experimentally can be very demanding because of the very precise definition of these quantities in standard DEB theory (see Kooijman's DEB theory). However, with certain information-rich data, it is possible to establish the full mass balance of C, H, O and N for each transformation (Kooijman., 2010). This becomes an issue of considerable practical importance in applications. For example, Brown et al. (2004) and Meer (2006) states that DEB models are complex, using many variables and functions. He claims that there is room for a complementary and even more general approach. This apparent complexity and intractability may have hampered widespread application and testing of DEB models (Meer, 2006).

In conclusion, SFG and DEB approaches share the same goal, that is, to describe the energetic processes of an organism. However, the conceptual foundation is different in each case.

Assuming that the specific hypotheses of both approaches are valid, SFG and DEB models should be able to successfully represent the real world, and consequently provide similar results in agreement with the observations. Therefore, from a practical point of view, both modeling approaches require the translation of the hypotheses into mathematical equations and the parameterization of those equations according to the environmental conditions. Model parameterization is one of the most challenging steps in the development (Filgueira et al., 2011).

2.5.4 Approach based on functional trait or performance rates

De Bello and al, 2010, defined a functional trait as a characteristic of an organism, which has demonstrable links to the organism's function. As such, a functional trait determines the organism's response to pressures (response trait), and its effects on ecosystem processes or services (effect trait).

Functional traits are considered, as reflecting adaptations to variation in the physical and biotic environment and trade-offs (ecophysiological and/or evolutionary) among different functions within an organism. In plants, functional traits include morphological, ecophysiological, biochemical and regeneration traits, including demographic traits (at the population level). In animals, these traits are combined with life-history, behavioural and feeding habit traits.

The functional ecology of animal communities is still in its infancy compared to the functional ecology of plant communities. For instance, for the last 5 years (2012–2016), there have been four times fewer publications on functional diversity of fish communities than on functional diversity of plant communities (Villéger et al., 2017).

Functional traits, used to assess fish, include traits measurable from observations on living individuals, morphological features measured on preserved organisms or traits categorized using information from the literature. In the present study, attention will be focus into functional traits or performance functions, adopted to assess the growth of reared species, as it's the case of sea bream at farmed conditions. The production system is aimed to provide the requirements and conditions needed for the culture species to grow.

In the following section is listed the basic performance traits, where description is given for the feeding rate and growth rate prediction for sea bream as a function of fish body weight and water temperature:

(i) growth rate, (ii) feeding rate, (iii) respiration rates (oxygen demand and CO_2 production), and (iv) excretion rate (ammonia and solids). A special attention will be dedicated for the first functional traits.

2.5.4.1. Growth rate

Growth rates in aquaculture are typically described by a specific growth rate (SGR) or absolute growth in g per day. Temperature affects growth, as in all poikilotherms, which increases as the temperature increases to an optimum. Above this optimum, growth decreases until the upper lethal temperature is reached.

Although SGR and absolute weight gain depend on feed intake and water temperature, they mainly depend on the size of the fish. As a result, growth among groups of fish of different weights cannot be directly compared (Lupastasch and kissil, 2003). The growth rate variability is firstly linked to species of fish and secondly to environmental conditions and production system.

Variability of the growth rate is well illustrated in Atlantic cod (*Gadus morhua*), a commercially exploited ground fish species inhabiting diverse environments and widely distributed in the subarctic and temperate waters of the North Atlantic (Dutil et al., 2008). Growth rate in cod varies among individuals at all stages of their life cycle, with growth during the early months or years having a lasting influence on sizes-at-age over life (Krohn and Kerr 1997; Armstrong et al. 2004). Growth in cod also varies seasonally and from year to year with or without a trend in the time series (Dutil et al., 1999).

Growth rate can be expressed as weight gain of fish fed to satiation and was described by Lupastasch and kissil (1998) by the following equations (2.15):

$$WG = \alpha_W \, W^{\beta w} \exp\{\gamma_w T\} \tag{2.15}$$

After integration of Equation (2.15) with respect to time, assuming constant temperature, the weight of a single fish at time t can be predicted by Equation (2.16)

$$W_t = \left[W_0^{1-\beta w} + (1- \beta w)\alpha_w \exp\{\gamma w T\} t\right]^{\frac{1}{1-\beta w}} \tag{2.16}$$

Where W is body weight of a single fish (g), WG is the weight gain (g per day) of that fish, T is water temperature (°C) and $\alpha_{w,}$ $\beta_{w,}$ and γ_w are species-species coefficients, for a specific temperature range and feed composition (Table 2.2).

2.5.4.2. Feeding rate

A similar equation (2.17) was proposed for feed consumption (feed intake, FI) to satiation of a single fish as function of fish weight (W) and water temperature (T) (Lupastasch and kissil, 1998).

$$FI = \alpha_f W^{\beta f} \exp\{\gamma_f T\} \tag{2.17}$$

Where FI (g feed/fish/day) is feed intake rate and α_f $\beta_{f,}$ and γ_f are again species-specific coefficient for a specific temperature range and feed composition (Table 2.2).

2.5.4.3. Feed conversion rate

Feed conversion ratio (FCR) as a measure of the fish efficiency in converting feed mass into increased body mass. It's calculated as the mass of the food eaten divided by the body mass gain. The FCR (g feed.[g fish weight gain]$^{-1}$ can be calculated by dividing the feed intake with weight gain (Equation (2.15) and (2.16) to result in equation (2.18) :

$$FCR = \frac{FI}{WG} = \frac{\alpha_F}{\alpha_W} W^{(\beta_F - \beta_W)} \exp\{(\gamma_F - \gamma_W)T\} \tag{2.18}$$

$\gamma F \cong \gamma W \cong 0.06$

For the case of the sea bream, where the temperature dependency coefficients for growth and feeding are similar in value, the FCR is approximately independent of temperature. Therefore, the feed consumed to grow fish to finalize is independent of temperature (Luptasch et al., 2003). FCR for large bluefin tuna in Mediterranean aquaculture (average initial and final weights of 219 and 255 kg, respectively) is as high as 7.4. Even though a somewhat lower FCR of 4.6 has been reported (Aguado-Gimenez and Garcia- Garcia, 2005) for smaller fish (average initial and final weights of 32 and 63 kg, respectively), it is still high in comparison to an FCR of 1 to 2 characteristics of other fish. From the bioenergetic point of view, high FCR is an indication that a large fraction of input energy from feed is lost in the form of heat and metabolic products that most likely originate from continuous swimming.

The DEB model, which includes cost of swimming in the somatic maintenance flux, captures these dynamics very well (Nisbet et al., 2012).

2.5.5 Standing stock biomass estimation and sea bream culture performance

A simplified model of "fish series" was used to demonstrate the concept of calculating standing stock biomass. The fish series is composed of series of fish at different weights where every day one fish at an initial weight W_0 is stocked at one end and a fish of weight W_t at t time is harvested at the other side. This model is simulating a production system where fish are stocked and harvested along the year.

If no mortality is assumed, then the number of days to grow from W_0 to W_t would reflect the number of fish present in this theoretical fish series at every moment. The biomass of the fish series could be calculated by a second integration of equation (2.19), which is Standing stock biomass estimation, (SSB calculated in kilogram, for fish weight expressed in gram) (Pavlidis and Mylonas, 2011).

$$SSB = \frac{{W_t}^{2-\beta w} - W_0^{2-\beta w}}{(2-\beta w)\alpha w \exp\{\gamma w T\}} \times \frac{1}{1000} \tag{2.19}$$

The fish species concept can be used to evaluate the effect of temperature on different requirements and design aspects of an intensive fish grow out operation.

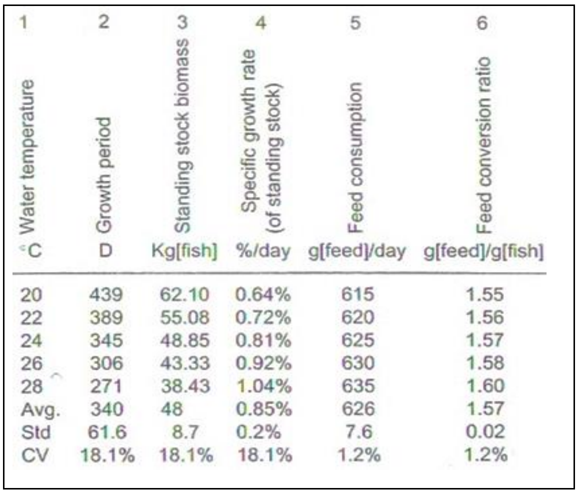
Table 2.2: Values of species-species coefficients, for a specific temperature range and feed composition, relative to growth and feeding rate

Coefficient	Symbol	Value	Units
Growth	α_w	0.024	-
	β_w	0.514	-
	γ_w	0.06	1/°C
Feeding	α_F	0.017	-
	β_F	0.652	-
	γ_F	0.064	1/°C

(Pavlidis and Mylonas, 2011)

In following example for sea bream (Table 2.3), the production is assumed to be one fish a day at its final weight of 400 g and stocking weight of 2 g. This example represents an optimal and ideal case of continuous stocking and harvesting that results in a production of 146 kg per year (1 fish of 0.4 kg x 365 days). The growth period and the standing stock biomass are reducing with the increase of temperature and the specific growth rate (of a fish and of the standing stock biomass) increases at 5 % for one-degree increase in water temperature. As an example, for a fixed feeding rate of 1.2% of the biomass, the FCR is increasing by 0.01 for every 2 degrees increase of water temperature.

Table 2.3: Fish series performances and requirements at different water constant temperature.



1 Water temperature °C	2 Growth period D	3 Standing stock biomass Kg[fish]	4 Specific growth rate (of standing stock) %/day	5 Feed consumption g[feed]/day	6 Feed conversion ratio g[feed]/g[fish]
20	439	62.10	0.64%	615	1.55
22	389	55.08	0.72%	620	1.56
24	345	48.85	0.81%	625	1.57
26	306	43.33	0.92%	630	1.58
28	271	38.43	1.04%	635	1.60
Avg.	340	48	0.85%	626	1.57
Std	61.6	8.7	0.2%	7.6	0.02
CV	18.1%	18.1%	18.1%	1.2%	1.2%

(Pavlidis and Mylonas, 2011)

Table 2.4 presents some production features of an ideal situation and more realistic situation of a 100 ton per year of sea bream farm, where the FCR in real production is 0,3 higer than FCR at ideal condition and for almost same amount of feed.

Table 2.4: Production performances and requirements of sea bream

	Unit	**Value for a "ideal fish series" producing 146 Kg per day**	**Value for "ideal" production of 100 ton per year**	**Value for "real" production of 100 ton per year**
Feed requirement	Kg feed per Day	0.626	429	500
Feed conversion ratio	Kg feed [Kg growth]$^{-1}$	1.57	1.57	1.82
Production rate	Kg per day	0.398	272.6	273

(Pavlidis and Mylonas, 2011)

2.6 Conclusion

During the last 10 years there have been important advances in productivity, caused by improvements in production technologies, that is, feeding systems automation, harvesting procedures, health management and selective breeding program looking at better growth rates are also carried out in gilthead sea bream since the early 2000s in France and Greece (Basurco et al, 2010).

This chapter resumed the most fundamental concept of models combining functional, bioenergetic and empirical relationships involved in the prediction and the control of the growth and biomass production of group of fish at the natural environment or controlled conditions. SFG and DEB concepts were not use on the present thesis, because from a practical point of view, both modeling approaches require parameterization of metabolic process, according to the environmental conditions, which is not possible under farmed condition, in open sea.

To foster a more complete functional approach for fish ecology, future research directions needs to incorporate functional traits describing food provisioning, while accounting more frequently for intraspecific variability and highlight ecological and evolutionary questions that could be addressed using meta-analyses of large trait databases. This framework could provide valuable insights on the mechanistic links between global changes, functional traits of fish assemblages, and ecosystem.

The growth of gilthead sea bream has been studied well in recent years and predictive models have been produced, using data from commercial farming in the Mediterranean Sea (Mayer et al. 2008). The aim is to propose in the next chapters a guide to how adequately assessing functional trait of fish communities and to present approaches currently used to describe the fish functions that determine their growth and performance.

CHAPTER 3

THE FUNCTION TRAITS AFFECTING THE GROWTH OF GILTHEAD SEA BREAM (*Sparus aurata*) FARMED IN MARINE CAGES IN TUNISIA UNDER REAL PRODUCTION CONDITIONS

3.1 Introduction

Gilthead sea bream and European sea bass aquaculture is widely established in the Mediterranean and North-eastern Atlantic regions, and rearing is mainly in coastal net-pen facilities. Differences in competitiveness among aquaculture facilities result, in part, from economic and environmental factors, which are conditioned by the geographical location of the facility. The location of production facilities influences business competitiveness due to environmental factors that affect the production process (Gasca-Leyva et al. 2002). There are many environmental factors that influence fish growth, for example, water temperature, salinity, light, and oxygen concentration dissolved in the water (Brett 1979).

As environmental factors influence fish growth, they affect the time required for the fish to reach the desired commercial size and in consequence they impact the costs associated with the cultivation process. Optimising the growth is one of the most important objectives for fish farms, while fish growth is assumed to be influenced by a variety of functional traits, including fish weight, feeding rates, growth rate, and conversion rate. Interactions between these functional traits and environmental factors might influence the prediction of growth in a farm environment. Understanding the influence of environmental, physiological and husbandry factors on fish production provide crucial information to maximize the growth rates of cultivated species.

The main objectives of this work were to evaluate which traits are more likely to affect fish performance, at the fish farm located at the south part of the Mediterranean Sea. Firstly, the focus was on the effects of temperature on the functional traits, specifically, feed conversion rate and specific growth rate and the specific feeding rate. Secondly, these functional traits were performed through different classes of weight of fish to distinguish if there are some significant correlation or dependency.

3.2 Materials and methods

3.2.1 Experimental facilities

The studied system is an offshore sea-cage aquaculture farm, implanted in area of 40 ha and a depth varying from 35 to 40 m, along the sea, located on the eastern coast of Tunisia, at three miles of the harbour facilities and delimited by A, B, C and D as pointed out in figure 3.1. The aquaculture farm is one of the oldest productive aquaculture farms in Tunisia and having a great experience on the on-growing red tuna. Total capacity of production is 1000 tons, specializes in rearing European seabass and gilthead seabream. Fingerlings of both species are mainly from local hatchery or imported, principally from Italy or Spain.

The aquaculture farm under study constituted by 20 circular net-cages (12 cages of 29 m and 8 cages of 19 m of diameter). The cages of 19 m of diameter are used mainly for pre-growing period and cages of 29 m for on-growing period and until harvesting time.

The farm is equipped with 3 boats (for feeding and fishing) and land-based facilities for administration and stock for feed and materials.

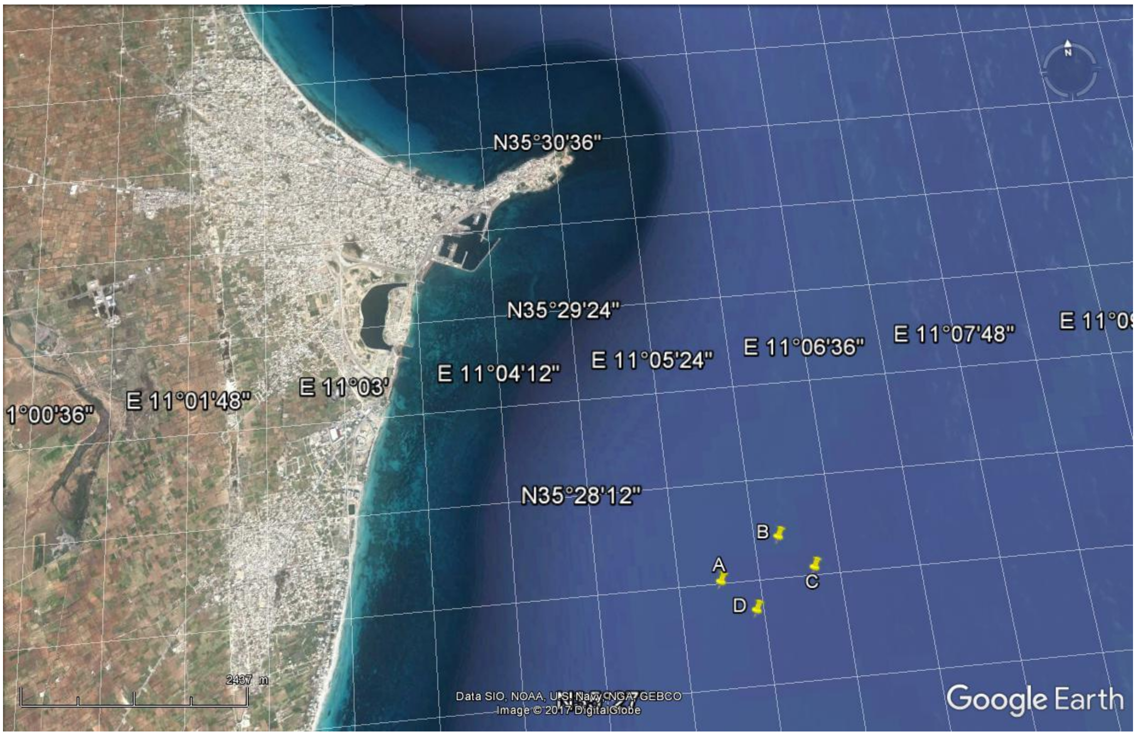


Figure 3.1: Geographic position of the fish farm, case of study in south Mediterranean Sea, eastern coast of Tunisia

3.2.2 Data collection

Twenty-one cages of sea bream, *Sparus aurata,* were monitored over their production cycle each, during six years from 2010 until 2016. Production cycle of cages varied from 6 to 24 months, depending from the initial weight sizes and technical management (Table3.1). Every cage contained on average of 350 000 fry. At the beginning of the rearing cycle, fish are counted and weighted by the supplier usually by counter (infrared scanner), with an accuracy of 95-98 %. Fish are conditioned to a commercial diet and every stage of growth of fish has a specific size and type of diet to cover their physiological requirements. Size of pellets of feed varied from 1.3 to1.5 mm for fry, 2 mm for pre-growing stage, and 3 to 4.5 mm for the on-growing stage. The feeding ratio is usually provided by the producers of feed, where feeding tables are based on size of fish and temperature of the water (Table 3.1). Real quantity of feed distributed can be adjusted according to real condition (bad weather, turbidity…). Fishes fed *ad libitum* at the beginning and specially for the fingerlings stages and tend to align with the theoretical feed quantities recommended by the feeding table according to the type of the diets. Feeding distribution can be completely stopped if the fish show a lack of appetite. In the first phase of growth, feed was distributed by hand, and afterwards using pneumatic canyons installed in the boats.

Table 3.1: Feeding table: Variation of feeding ratio according to water temperature and weight of fish (Kg of feed per 100 Kg of biomass per day)

Fish (g)	**MM**	**Water temperature (°C)**								
		12	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**
20-50	3	0.58	0.81	1.1	1.46	1.94	2.59	3.08	3.24	2.92
50-100	3	0.47	0.65	0.88	1.17	1.56	2.07	2.46	2.59	2.33
100-200	4.5	0.37	0.51	0.7	0.93	1.23	1.65	1.95	2.06	1.85
200-400	4.5	0.30	0.41	0.56	0.74	0.99	1.32	1.56	1.65	1.48
>400	6	0.24	0.33	0.44	0.59	0.78	1.05	1.24	1.31	1.18

During the rearing cycle, the fish are weighted, every 30-40 days or 60-90 days maximum. A sample of minimum 100 fish is caught randomly and weighed individually, fish by fish. Harvesting time starts at mean weight of 200-250 gr. At each harvest, fishes are calibrated on five classes from the small to the big size (SS<200 g, S: 200-300 g, M: 300-400g, B: 400-600g, BB>600gr).

Physic-chemical parameter is measured every day, with a multi parameter instrument, which provides temperature (accuracy ±0.2), oxygen (±0.5% of the value) and pH (± 0.0004) of the sea water.

Table 3.2 illustrated the initial and final weights, the number of weight sample and the final FCR, as an indication about the performance of the twenty-two cages. Cages are identified by batch number, indicating the year of the beginning of the rearing cycle on the cages.

Table 3.2: General data sets describing initial, final weight of twenty-one cages, FCR and sampling details

Cages	Initial weight (g)	Final weight (g)	Cycle (days)	Final FCR	Number of measurement	Frequency of measurement of weight
1-2010	21,8	205,3	301	2,02	22	during harvesting time
2-2010	49,2	237,1	206	1,85	21	during harvesting time
4-2010	27,4	215,4	235	2,15	13	during harvesting time
5-2010	4,8	192,6	491	2,32	32	during harvesting time
1-2011	10,3	173,3	507	2,00	25	monthly during the whole cycle
1-2012	3,4	276,6	534	3,86	22	monthly during the whole cycle
2-2012	3,8	268,2	506	4,66	20	monthly during the whole cycle
3-2012	4,3	312,0	500	1,73	24	monthly during the whole cycle
1-2013	13,6	190,3	476	2,19	16	monthly during the whole cycle
2-2013	11,3	195,6	433	2,14	17	monthly during the whole cycle
3-2013	9,0	184,0	401	1,63	14	monthly during the whole cycle
4-2013	8,9	207,2	480	2,07	20	monthly during the whole cycle
5-2013	5,5	204,1	497	2,01	17	monthly during the whole cycle
6-2013	4,9	169,9	448	2,10	18	monthly during the whole cycle
1-2014	4,9	288,0	726	2,04	31	monthly during the whole cycle
2-2014	2,9	221,0	719	2,07	26	monthly during the whole cycle
3-2014	3,2	247,3	686	2,00	26	monthly during the whole cycle
4-2014	3,7	261,2	689	1,94	26	monthly during the whole cycle
1-2015	3,3	270,3	478	1,90	24	monthly during the whole cycle
2-2015	3,8	310,4	527	1,90	28	monthly during the whole cycle
3-2015	3,2	370,9	553	2,05	14	monthly during the whole cycle

3.2.3 Studied Parameters

The monitoring of cages was done daily for basic activities: Parameters controlled, on daily basis, were temperature, quantity of feed needed and distributed per day, mortality control and nets control. A monthly adjustment based on the sampled weight, was conducted to calculate the corresponding functional traits.

Performances rates used for evaluating the growth, are computed for each cage (Table 3.2), to study their evolution and inter-dependency, from temperature.

Performance rates of functional trait were, Specific feeding rate (SFR), specific growth rate (SGR), feeding conversion ratio (FCR), biological conversion rate (BCR) and weight gain (Wg), were calculated using equations (3.1), (3.2), (3.3) and (3.4) as functions of daily feed intake (DFI), cumulative feed intake (CF) for a period of time, initial body weight (Wi), final body weight (Wf), weight of fish harvested (Wh), weight of fish dead (Wm), number of fish (N) at given time, initial number of fish (Ni), final number of fish (Nf), number of fish dead (Nm), number of fish harvested (Nh), weight of fish at time t (W_t), weight of fish at next sample (W_{t+1}) and (ΔT) period of time between two measurements.

$$SGR = \frac{\log(wf) - \log(wi)}{\Delta t} \tag{3.1}$$

$$SFR = \frac{\frac{DFI}{N}}{Wf} \tag{3.2}$$

$$FCR = \frac{CF}{NfWf - NiWi + NhWh} \tag{3.3}$$

$$BCR = \frac{CF}{NfWf - NiWi + NhWh + NmWm} \tag{3.4}$$

$$W_g = W_{t+1} - W_t \tag{3.5}$$

Heterogeneity of the data must be raised, as it was a limitation related to the time irregularity of the monthly weight sampling data. For complete and coherent series of observations, the arrangement adopted and judged to be the closest to reality was to calculate the average of the food ration, during each period elapsed between two successive weight measurements. In this way, each series of observations includes a measure of the average weight and the corresponding mean specific feed ratio. Dataset were computed for the 21 cages and used for descriptive analysis. The descriptive analysis concerns nine cages reported in the table 3.3, which were selected based on final FCR and BCR for a given final weight, as criterion of choice.

Table 3.3: Examples of cages identified by an adequate FCR and BCR and used to illustrate the evolution of the different performances ratio in relation to time

Cages	Initial weight (g)	Final weight (g)	Final BCR	Final FCR
1-2011	10,3	173,3	1,91	2,00
1-2012	3,4	276,6	1,93	3,86
3-2012	4,3	312,0	1,73	1,73
4-2013	8,9	207,2	2,05	2,07
5-2013	5,5	204,1	2,00	2,01
1-2014	4,9	288,0	1,95	2,04
4-2014	3,7	261,2	1,80	1,94
1-2015	3,3	270,3	1,89	1,90
2-2015	3,8	310,4	1,90	1,90

The nine cages can be considered representative because the BCR recorded varied from 1.80 to 2.00 at most of the time. The difference between FCR and BCR is the biomass of the mortality or the biomass lost. It should be noted that the simple classification criteria were fixed to identify the choice of cages.

Weight of fishes were represented as function of time and temperature, to evaluate the evolution of the growth. The same was done for the trait functional, to demonstrate if there are any relationship or correlation. Curves of the different performance rates (FCR, SGR) and the husbandry trait (SFR), were represented according to different classes of water temperature, and fish weights classes.

3.2.4 Statistical analyses

Sampled weight data of the 21 cages, used to compute all functional trait of growth, have generated 468 data for each functional trait.

The standard error of the mean of each parameter was estimated as the sample standard deviation divided by the square root of the sample size (assuming statistical independence of the values in the sample). Standard errors provided simple measures of uncertainty in each value and was used to determine a confidence interval. The standard error is considered part of descriptive statistics. It represents the standard deviation of the mean within a dataset. This serves as a measure of variation for random variables, providing a measurement for the spread. The smaller the spread, the more accurate the dataset is said to be. Based on the standard error of the mean only 277 data, were kept for next statistical analysis. Normality test was conducted to determine if data sets was well-modeled by a normal distribution.

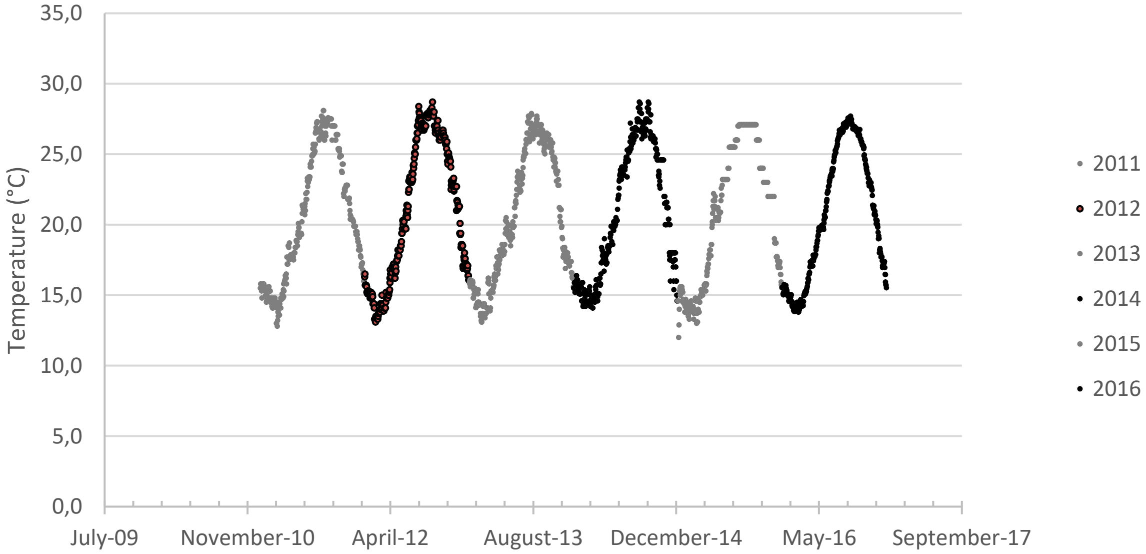
Demonstrating that dataset did not follow a normal distribution a standardization of data was run before the test of the Principal Component Analysis (P.C.A) was performed, using IBM SPSS 25.0. Significant difference between functional rates, husbandry parameter and temperature, were determined by KMO and Bartlett’s Test range at $p<0.05$.

3.3 Results and discussion

3.3.1 Monitoring of the temperature

The temperature was measured every day in the fish farm to determine the feeding rate to apply per cage, according to the table 3.3 of feeding rate, where, for each temperature range and a given weight, there was a recommended feeding ratio.

Annual variability of temperature from 2010 till 2016 is presented in figure 3.2. Temperature fluctuated from 12°C to 28 °C, where 12°C was the lowest daily temperature recorded during February and March, and 28°C, characterised the highest temperature recorded in August or September. Temperature variation, through the six years, was slightly the same, except some differences. In July 2012, the highest temperature of 28,4 °C was recorded, while the average temperature, for July was 25,9 °C. In 2015, temperature decreased considerably during beginning of January by 1°C, every two days, to reach a minimum of 12°C, while this minimum was typically the lowest water temperature recorded in February or March. In 2014, a peak of 28.7°C was recorded twice, in August and in September while for the other years the highest temperature is more stable and had a progressive evolution.



Figures 3.2: Annual temperature variation from 2011 till 2016

Literature reported that temperature conditions, in area designated to produce sea bass, *Dicentrarchus labrax,* differ across regions. For instance, the average temperature in south Turkey is about 21 °C, with a difference of 10.6 °C between winter and summer.

For Tunisia, the temperature average is about 21 °C, but with a difference of 14°C. In north western Italy, the average temperature is 18 °C and the difference is 9.5 °C (Llorente and Luna, 2013). For sea bream and sea bass, optimal growth is around 24 °C (Person-Le Ruyet et al., 2004). Consequently, the time required to reach harvest weight, and therefore, costs associated with fish farming vary across regions (Gasca-Leyva et al., 2002). Llorente and Luna (2013) showed that the difference in water temperature between areas in the Mediterranean Sea is a major source of competitive advantages for fish farms.

A higher annual average temperature generates faster growth and enables farmers to either produce more batches, or alternatively, bigger fish in a given production system. A lower seasonal difference is associated with less extreme summer and winter temperatures, closer to the optimum, resulting in better feed conversion ratio (Llorente and Luna, 2013). In Tunisia, it’s possible to consider that the highest difference between water temperature was recorded compared to Italy and Turkey, which lead to conclude that it might affect negatively the optimal feed conversion rate, reached. In the next sections, descriptive analysis was done to study the effects of water temperature fluctuations on the performance rates and the feed consumption.

3.3.2 Descriptive analysis of the growth

In the following figure 3.3, the growth is represented, according to time for the nine cages selected (table 3.3). Most of the growth curves of cages are significantly nonlinear, except the generation of 2013, where the growth appeared much more linear than non-linear (figure 3.3). The growth is significantly reduced during the winter time, starting from December in most of time to restart again at the spring time (April- May). Cage 1-2011 presented a very slow growth during the firsts months, compared to the other. In 8 months, fishes of cage 1-2011 weighted 50 g, while for cage 1-2012, the same weight was recorded in 4 months and 100 g, in on 8 months. In fact, the growth did not evolve in a proper way among the time from April to November, while the temperature varied from 17-18 °C to 20-22°C, respectively, and reached an optimum, between the two intervals.

The best performance is to maximze the growth and to minimize the feed conversion ratio (Jauralde et al, 2013). The fish growth of cage 1-2011 was not well performing and the final weight reached in almost 17 months was only 178.9 g, with FCR equal to 2.

The most performed cages are lot 1-2012, 3-2012, lot 4-2013, lot 1-2014 and 1-2015, having the same growth behaviour and attempting the same size level in almost the same period. On top of the level lot 1-2014, reach 100 g only in 4 months, then the growth decreased and remained stable from January to March which correspond to an average temperature of 15 °C, where the growth is almost stopped.

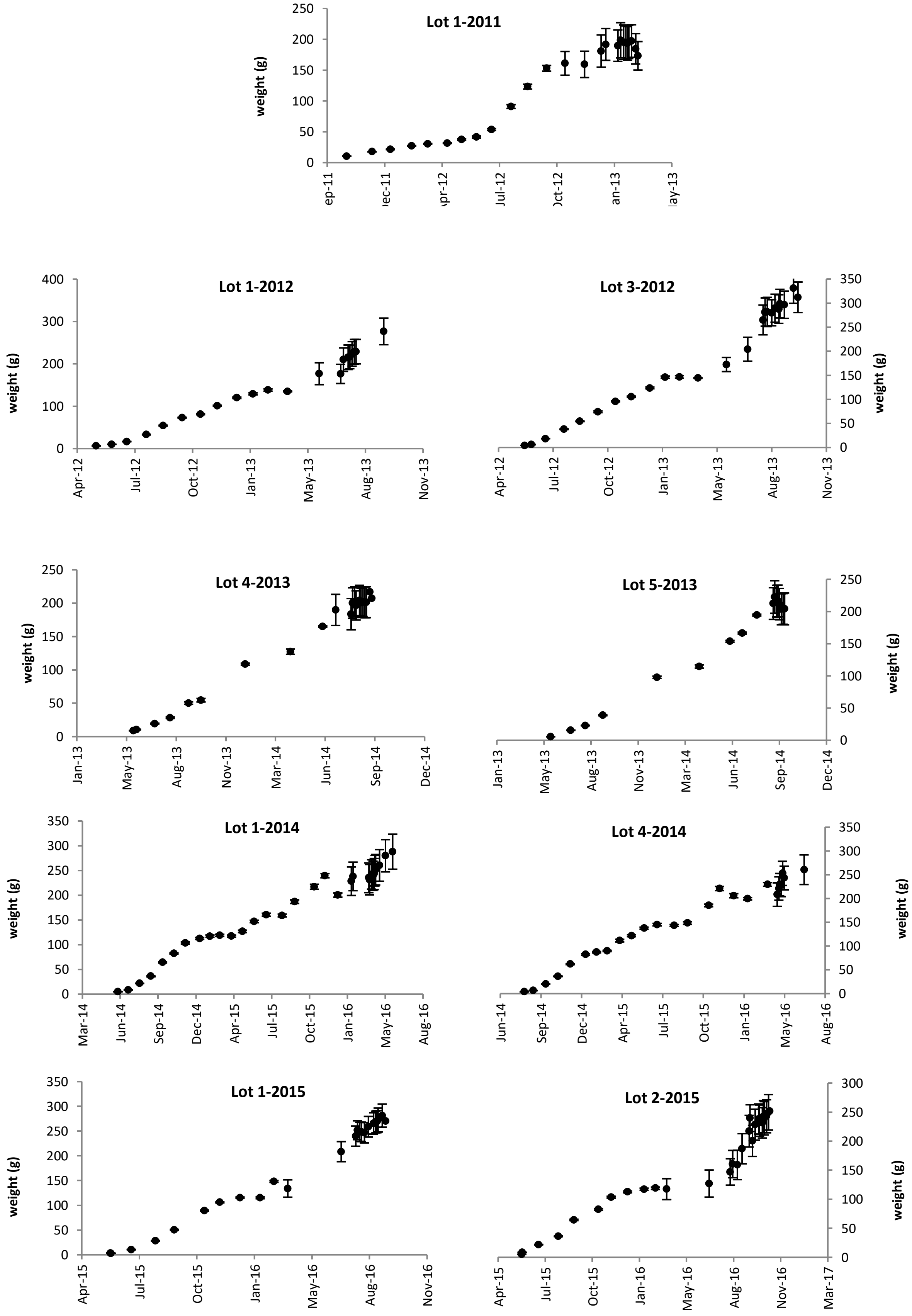
To evaluate the effect of temperature on the growth, the weight gain was a good functional parameter to consider how it was varying according to temperature fluctuations (Figure 3.4). At low water temperature, the vertical distribution reflected the stability of the weight gain, while the horizontal distribution, which occurred mainly during the interval of optimal temperature [25-30°C], supported the argument of the high dependency of the weight gain from temperature variation. For the cage 1-2011, the effect of temperature was more obvious, as the weight gain tended to reach a maximum around the optimal water temperature of 25°C and increased, when the temperature remained at the highest level from 25 to 27.7°C. According to Stauffer (1973), three are the major independent variables involved in growth: ration size, fish weight, and the water temperature. Accordingly, one of the most frequently studied environmental factors is water temperature, viewed by several authors as the most important environmental influence on growth and the feed conversion rate (Hernandez et al. 2007; Brett and Groves 1979). In seabream production, optimum water temperature is near 25° C.

Growth diminished progressively above and below this temperature, until halting at the minimum temperature of 12°C, and the maximum of 32.9°C (Llorente and Luna, 2013).

The more interesting weight gain obtained, were the ones recorded at sampling interval of 30 days. Cages of 2013, (4-2013 and 5-2013), recorded the highest values of weight gain at 15 °C, which was not really linked to temperature but to the time intervals between weight measurement of 90 days, which should not be considered as reference case.

A big variability can be noticed on the weight gain of cage 1-2015 and 2-2015, around the optimal water temperature (25°C), due to the same reason.

To exclude the effect of time, on the growth, the specific growth rate presented in the follow section is more accurate to put in evidence that fish are ectotherms with a remarkably plastic and highly variable growth rate, depending on water temperature in particularly, as environment condition factor (Dutil et al., 2008).



Figures 3.3: Growth of gilthead sea bream among the production cycle

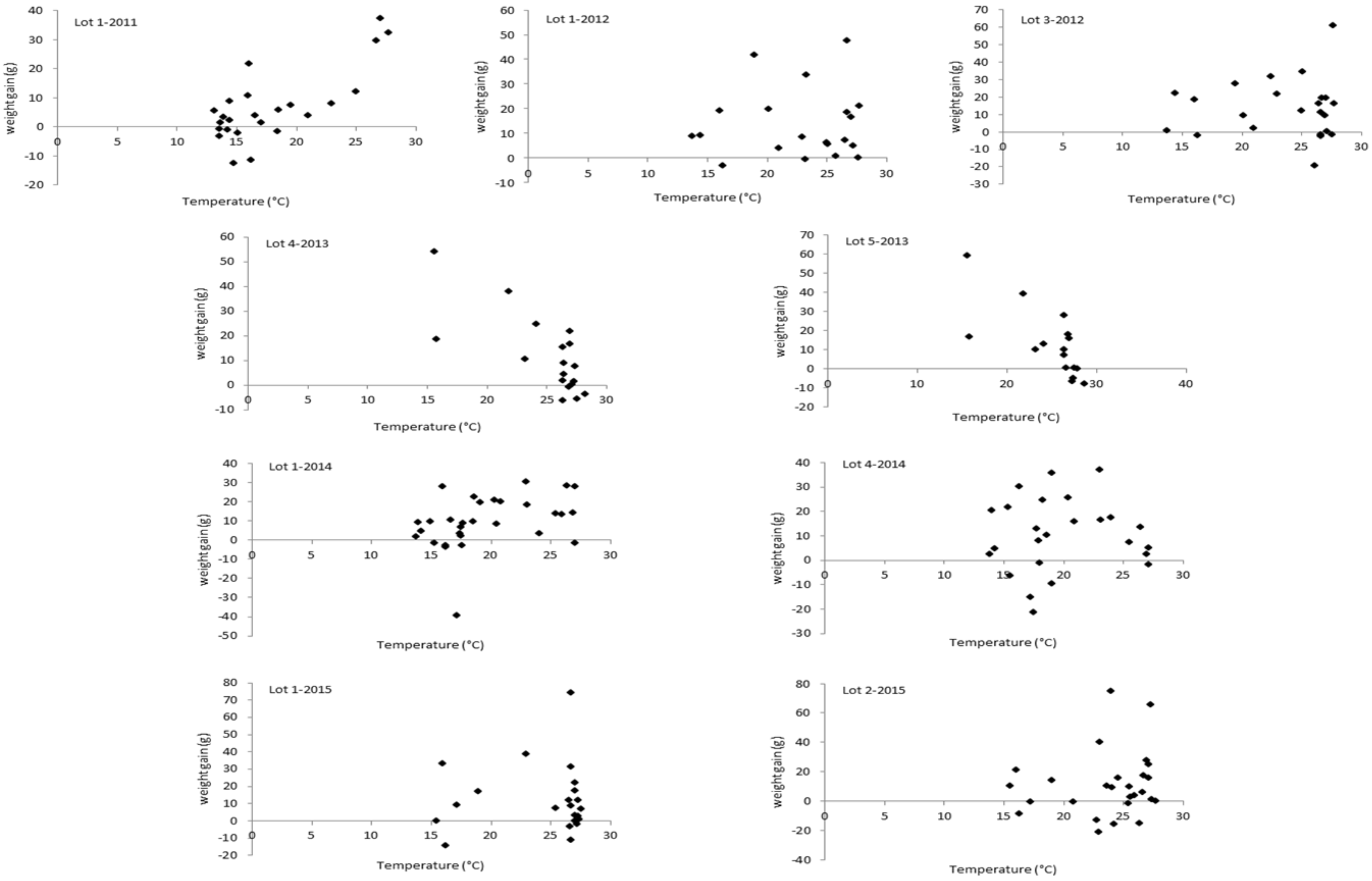


Figure 3.4: Weight gain of Gilthead sea bream as function of water temperature

3.3.3 Descriptive analysis of the specific growth rate

The relationship between specific growth rate and temperature is mainly illustrated on cages 1 and 3-2012, 1 and 5-2013, 1and 4-2014 (figure 3.5), where the highest level of SGR was recorded at the highest range of temperature, specifically during the first stage of pre-growing. SGR was equal to zero or having a negative value recorded in cage 1-2015, during the lowest temperature range, varying from 15 to 20 °C. The relationship between fish growth rate and temperature is dome-shaped, with a maximum growth rate at an optimal temperature depending on food availability and body size, as it was also demonstrated by Bjornsson et al, (2001). In un-limited food conditions, an increase in temperature up to the optimal value results in an increase in growth rate (Purchase and Brown, 2001). In most fish species, individual growth rates are largely determined by temperature (Pauly, 1980; Bjornsson and Steinarsson, 2002; Buckley et al., 2004; Britton et al., 2010). Understanding the implication of temperature on growth could lead to a better forecasting of stock biomass (Baudron, 2011). Temperature has a major impact on farm management and productivity for two main reasons. Firstly, fish are poikilothermic animals, implying that their metabolic activity and growth depend on ambient water temperature. Secondly, changes in water temperature generate variation in oxygen supply because warmer water can hold less dissolved oxygen which is vital for fish growth (Thetmeyer et al., 1999; Pichavant et al., 2001; Besson et al., 2016).

Growth rate is considered the most important trait by fish farmers (Sae-Limet al., 2012; Besson et al,2016) and is consistently part of the breeding objectives. A lower amplitude reduces the periods where fish are exposed to extreme (higher or lower than 24 °C) temperature conditions at which growth is reduced (Besson et al., 2016). Body size has a direct influence of the effect of temperature on fish growth because at the optimal temperature for growth, food conversion decreases with increasing body size (Àrnason et al., 2009).

In sea cages, fish are exposed to variations in water temperature, which has two consequences: variation in metabolic rate and feed intake and variation in oxygen supply across the year. An increase in water temperature, increases the oxygen demand, because of an increase in feed intake, but decreases the oxygen supply.

As a result, dissolved oxygen may become a rearing constraint during the production cycle when the oxygen requirement of the fish is higher than the supply.

In summer, high temperature generates high growth hence high oxygen consumption, together with limited oxygen supply.

Therefore, these periods are the most constraining regarding stocking density, which might explain the variation of the SGR according to time and the difficulty to detect a direct dependency on temperature fluctuations. It’s possible to notice that during the first summer, where the temperature reaches an optimal and increase continuously to maximum limit before to decrease progressively, SGR had reached an optimal at this early stage of the on-growing cycle for the majorities of the cages. During the second summer, fishes were not able to reach the same level of growth rate, which can be linked to the stoking density and independently from the impact of the individual weight.

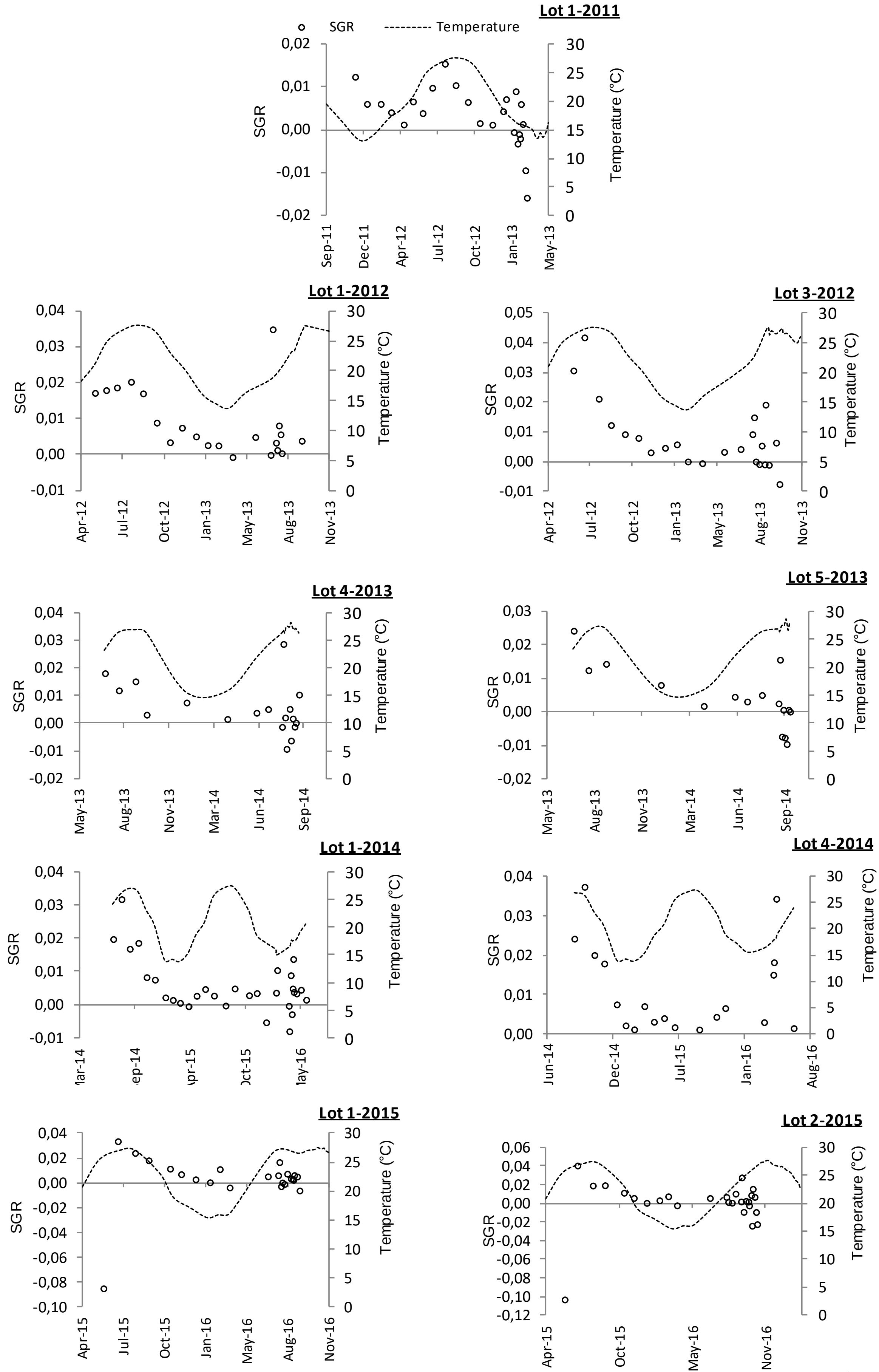
Besson and al,2016 explained that When a batch went through two summers, the day when oxygen consumption of the batch equaled oxygen supply (Dlimit) occurred during the second summer when the fish reached harvest weight. Therefore, individual oxygen consumption was high at Dlimit, which in turn, strongly constrained the initial stocking density.

3.3.4 Descriptive analysis of the specific feeding rate

High values of specific feeding rate were recorded during the beginning of the cycle, when temperature was at the maximum. During the second year, at the same intervals of temperature, SFR was not reaching the maximum, as it’s was at the earliest stage but remained around 0.01 and 0.02 (g [feed]/g[BM]). It’s linked to the fact that fingerlings demand is higher. At the fish farm, they were fed generally ad libitum for several rations per day (from 3 to 6) and at advanced stage were fed ones to twice per days, maximum.

When temperature decrease, SFR tend to decrease generally because the metabolic needs of fishes, as poikilotherms organisms, decrease. The amount of feed intake serves for maintenance and locomotion of the fish (figure 3.6).

Feed composition is assumed fixed throughout the fish-farming process. Therefore, diet quality is not considered a decision variable for fish producers (Hernandez et al. 2003). The optimal feeding trajectory has been studied in numerous previous papers (Cacho et al. 1991; Mistiaen and Strand 1999; Llorente and Luna, 2013). Accordingly, it is assumed that the ration sizes recommended by feed suppliers are at optimal levels, but effective feeding of farmed fish poses several problems: the feeds are exposed to water prior to being ingested, so they must be water stable with minimal loss of nutrients.



Figures 3.5: Water temperature (°C, Dashed line) profiles and specific growth rate (g.day^{-1}, Dots) trajectories for various groups of cages

Disintegration of feed will make it unavailable and leads to undesirable water fouling. There are numerous factors that interact to influence feeding, therefore, it is extremely difficult to predict when and how much a fish will eat. A large proportion of the cost of aquaculture production is related to feeds and feeding, so feeds must be correctly formulated, and the quantities given to the fish should meet demand, without excessive wastage (Jobling, 2011).

When feed assessment studies are conducted, it is important to collect accurate information about food intake. In fish farm cage, it is very difficult to collect the waste of feed to get information about the amount of food eaten by a group of fish. The only possibility is to consider the feeding conversion ratio because it reflects the amount of feed converted into biomass, if the conversion of 1 kg of biomass, required more than 2 kg of at certain stage of the on-growing cycle, this is mean that feed intake was not used for the growth but simply lost into waste or used to cover other metabolic activities.

It's admitted that specific feeding rate of the cages follows the seasonal fluctuations of water temperature. The highest levels of SFR are recorded during the highest range of temperature, to decrease progressively as the temperature decreased, which reflect also the deceleration of the metabolisms activities.

3.3.5 Variabilities of specific growth rate and specific feeding rate according to water temperature fluctuations

Specific growth rate response was correlated to the specific feeding rate, based on the curves represented on the figure 3.7. The optimal SFR, corresponded to the highest growth rate recorded, during the whole on-growing cycle. Figure 3.7 showed that SGR was negative or equal to zero during winter time and the SFR recorded at the same period was very low. For certain batch, for instance batch 1-2014, SFR and SGR were almost equal, which might correspond to an optimal feeding conversion ratio.

High feed intake promotes fast growth and is also associated with efficient utilization of feed resources (Bergheim and Åsgård, 1996; Einen et al., 1999; Oehme et al., 2012). Because the water temperature and feeding rates are considered deterministic, the weight of the fingerlings defines a single trajectory of growth until the selected harvest weight is attained (Llorente and Luna, 2013).

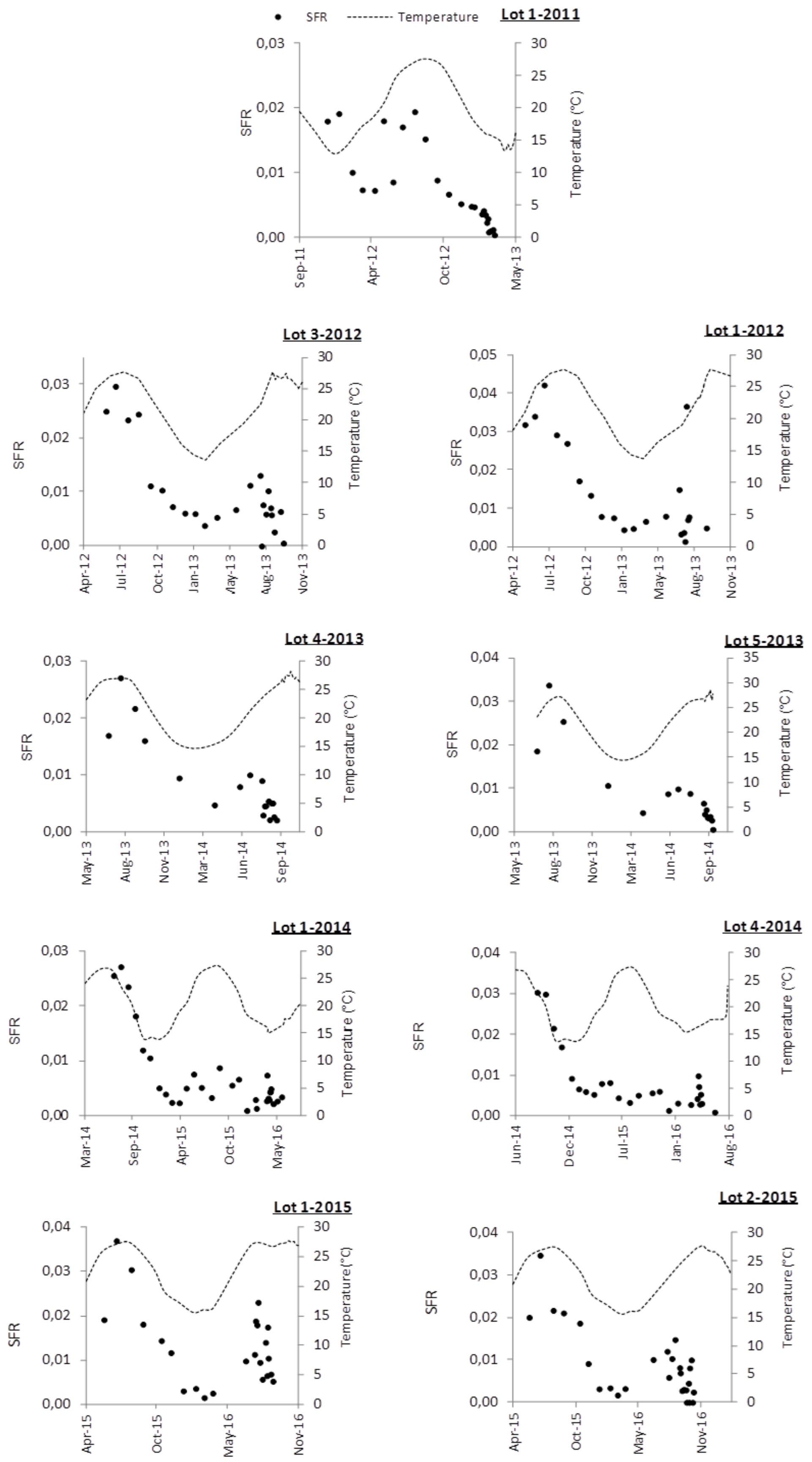


Figure 3.6: Relationship between temperature (°C, Dashed line) and specific feeding rate (g [feed]/g[BM], Dots) of Gilthead sea bream

Therefore, feeding practice such as ration size and the temporal and spatial delivery of feed should be adapted to the feeding habit and appetite of the fish (Talbot et al., 1999; Oehme et al., 2012). A suboptimal feeding practice may cause underfeeding, reduced growth, increased competition among fish, size variation, economic loss and nutrient discharge to the environment (Einen et al., 1995; Kadri et al., 1996; Noble et al., 2008; Talbot, 1993; Talbot et al., 1999; Oehme et al., 2012). Feeding practices also affect aggression level and fin injury in salmonids (Oehme et al., 2012) and reduced fish welfare is directly linked to reduced feed intake and growth (Attia et al., 2012; Oehme et al., 2012). Thus, when feeding large populations of fish in sea cages, it is anticipated that spreading the feed pellets uniformly and over a large area is beneficial to maximize feed intake and minimize aggressive behaviour (Attia et al., 2012; Kadri et al., 1996; Oehme et al., 2012).

In order to facilitate high feed intake (Talbot, 1993; Oehme et al., 2012) and to avoid generation of feed spill (Oehme et al., 2012), feeding rate, number of meals and feed distribution should be adjusted to meet the physiological and behavioral demand of the fish. Thus, in addition to a well-balanced diet, the feeding system and operation of the feeding system is essential.

Noble et al. (2008) reported that feeding regime and delivering of feed affected amount of feed spill and availability of feed under farming conditions in sea cages. These findings may suggest that feeding practice in large sea cages with high number of fish is of greater importance than in small tanks, which was the case of the studied fish farm, as the on-growing cycle was handled in cage of 29 m of diameter.

3.3.6 Relationship between functional traits, at different classes of water temperature

The frequently studied environmental factor is water temperature, viewed by several authorities as the most parameter, influencing growth and feed conversion rate (Hernandez et al. 2007; Brett and Groves 1979). This topic has been extensively studied in the case of sea bream (Mayer et al. 2008). In seabream production, optimum water temperature is near 25°C.

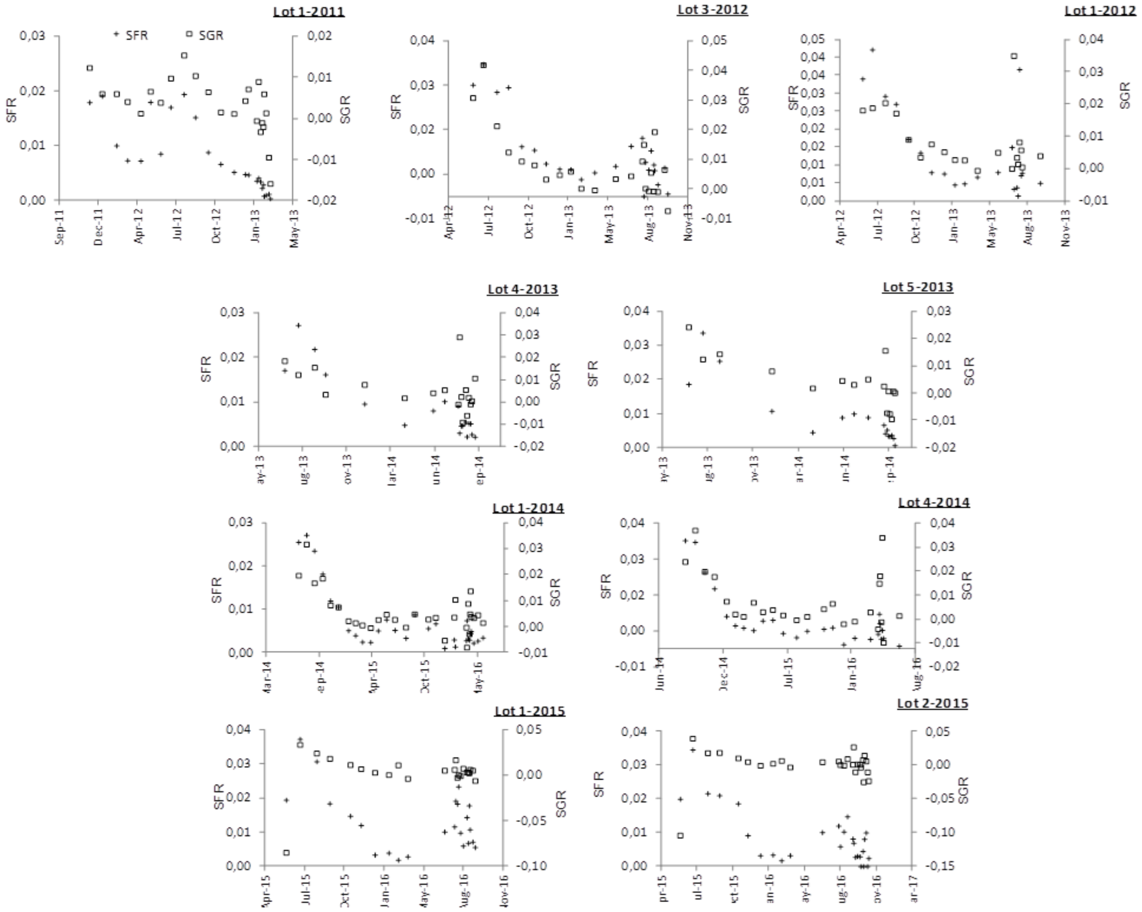


Figure 3.7: Relationship between specific feeding rate (g [feed]/g[BM]) (+) and specific growth rate (g.day^{-1}) (□)

Growth progressively diminishes above and below this temperature, until halting at the minimum temperature of 12°C, and the maximum of 32.9 C (Barnabe, 1991). Functional traits were studied through the temperature fluctuations from 12°C till 28°C. Every 2 °C of temperature, the feeding conversion rate was represented according to SFR and SGR, first and then the SFR as function of SGR. When temperature was at the interval of [12:20] °C, FCR varied from 1 to 3 %, and SFR ranged around 1%, which can be explain by the fact that feed conversion of fish is limited at low temperature independently from the amount of supply of feed. Around the optimal temperature (22-26°C), FCR was below 2 % and remained almost stable independently of SFR, despite that SFR increased up to 4 %. At high water temperature (26-28 °C), FCR increased, slightly above 2 %. Feeding conversion ratio, as function of specific feeding rate showed dependency only around the optimum water temperature, at the intervals of 22-28 °C, (figure 3.8).

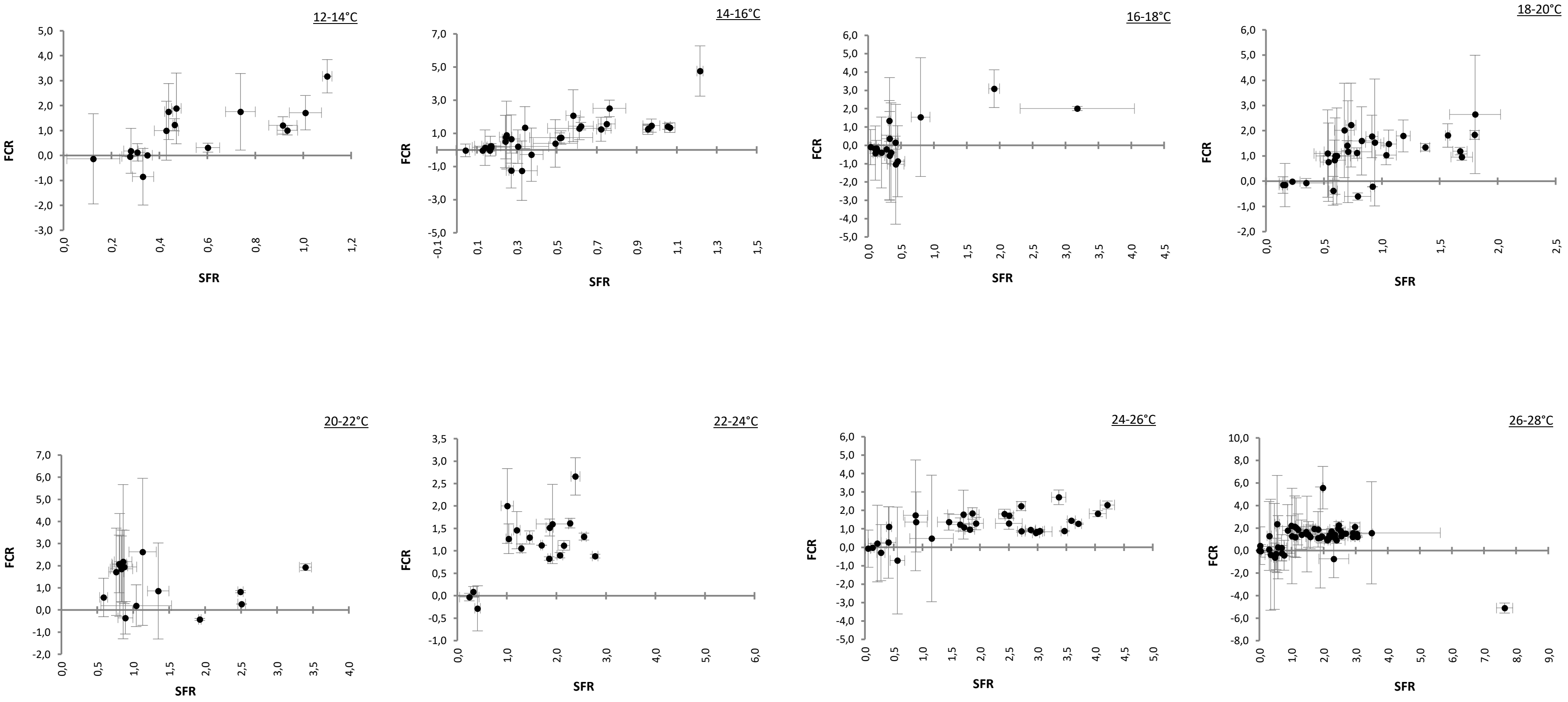


Figure 3.8: Relationship between feed conversion rate (%) and specific feeding rate (%.g [feed]/(g[BM]) at different classes of temperature (T°C)

In figure 3.9 (A), most of classes of temperature, from 22 to 28 °C, FCR had a decreased tendency, when SGR was increasing and after reaching a value of 0.02 (g. days^{-1}). Which means that if SGR increased, the weight of fish grew properly, and the feed conversion tended to be optimized. At low water temperatures, no relation between these two functional traits can be notified, compare to the significant correlation between specific feeding rate and SGR, at the optimum water temperature varying from 24-26°C. The general trend showed that SGR increased when specific feeding rate tended to increase. At low water temperature, 18-20 °C (figure 3.9 B), SGR remained almost stable at the interval of [0,0-0,02] g.days^{-1}, while SFR varied from 0.2 to 2 %.day^{-1}. Below 18°C, no significant relation between SFR and SGR was notified. Gasca-Leyva et al., (2002), who found that the lower range of water temperatures in the Canary Islands than in the Mediterranean Sea, demonstrated that the different ranges of water temperatures are also a source of differences in the competitiveness of the different seabream production areas in the Mediterranean Sea, which confirm the fact that growth rate depend on temperature range.

Some authors have reported on the effect of feed rate on specific growth rate, first in grass carp Ctenopharyngodon idella using linear regression (Cui et al., 1994).

Xie, et al., (1997) established an energy budget for tilapia fingerlings using asymptotic regression and developed a global model of specific growth rate and feed conversion ratio, as functions of feeding rate has been developed. Watanabe and al, (2000) studied energy and protein requirements by feeding Japanese yellowtail ranging from 8 to 300 g at several feeding rates, and they obtained some linear regression models of specific growth rate as a function of feeding rate for each size class. Eroldogan et al., (2004) determined the optimum feeding rate in European sea bass fingerlings and Klaoudatos and Conides (1996) reported a quadratic regression between SGR and feeding rate in gilthead sea bream. In our case, the relation between specific growth rate and specific feeding rate tended to be linear, as demonstrated in figure 3.9, around the optimal temperatures.

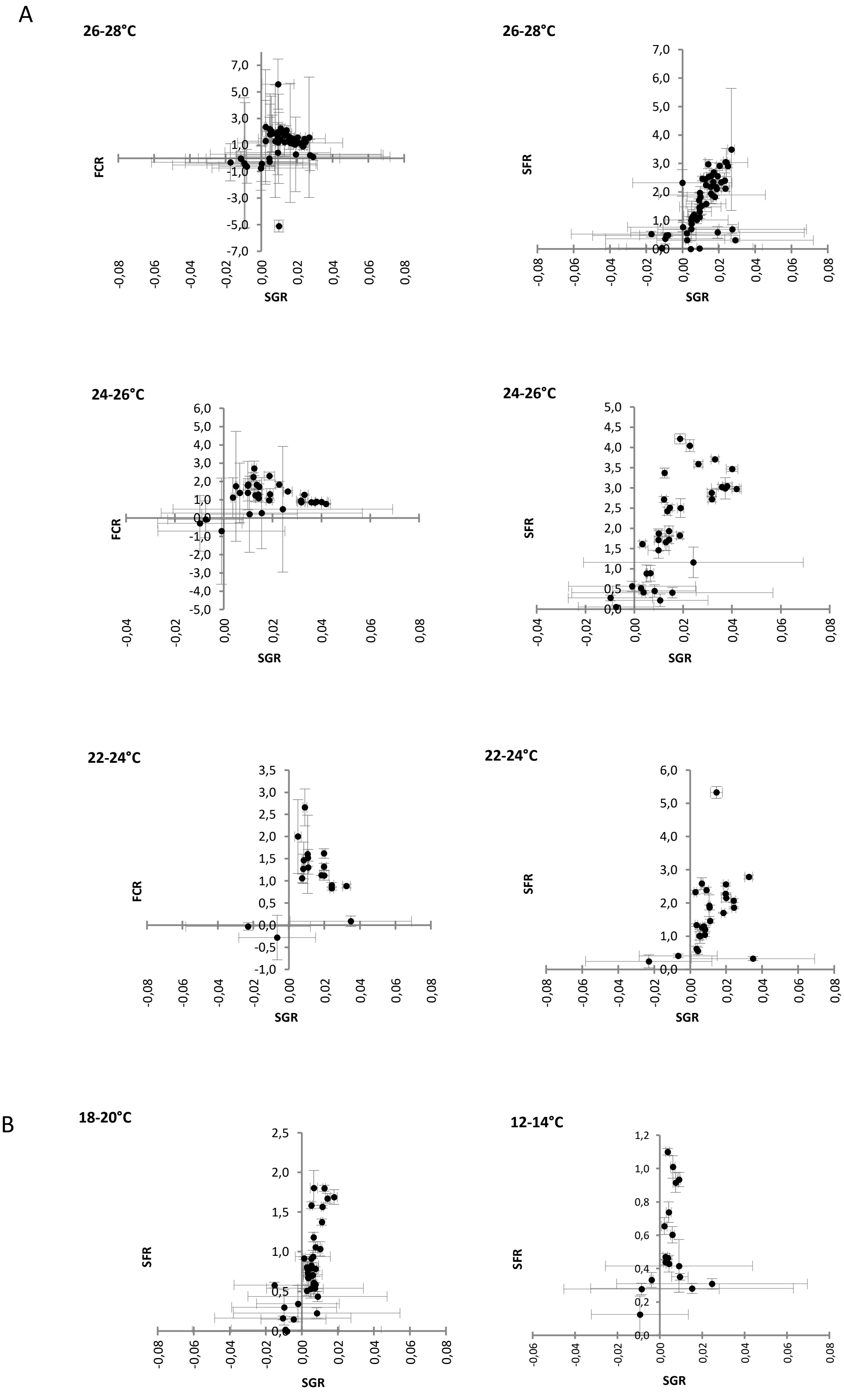


Figure 3.9: Relationship between FCR (%) and SFR (%.g [feed]/(g[BM]) with SGR (g.day^{-1}) at different classes of temperature T(°C). (A): optimum water temperature (22-28°C) and (B): low temperature of (18-12 °C)

3.3.7 Relationship between functional traits at different weight classes of fish

The effect of water temperature on SGR at different weight of fish classes should not be neglected. Figure 3.10 showed a significant dependency of temperature, at fish weight classes from 10 to 50 g, where the highest values of SGR were recorded around 25 °C, the optimum water temperature for the growth of sea bream. According to results showed, water temperature influenced the relation between FCR and SFR, and SGR, at early stages, for fish sized at 10-50 g.

No significant relation between SGR and temperature, at the intervals of 100 to 350 g. At this stage the harvesting activities started, which might stress the fishes and affect their growth.

For the classes of weight from 3 to 100 g, Figure 4.4 shows that FCR is under 2 % when SFR is between 2-4 %, which correspond to the maximum SGR of 0.04 $g.day^{-1}$ (figure 3.11). This is means that at these classes of weights of fish from 3 to 100 g, fish are able to grow faster and to better convert the feed into biomass.

For classes of weight between 100-350 g, SFR decreased compare to the previous classes of weight to range at 0-2%, which correspond to FCR equal to 2 % (Figure 3.11) and SGR, not high than 0.02 g.day-1 (figure 3.10).

The feed conversion rate, defined as the measure of the fish efficiency in converting feed mass into increased body mass: For instance, the lower the value of the rate, the greater the efficiency of cultivation. However, fish growth was slower or even zero during cold water periods. A higher range of temperatures allowed more continuous growth of the fish during the year. The feed conversion rate begins to increase due to lower water temperatures (Llorentel and Luna., 2013). According to the same authors, the production strategy is affected by the variability in the water temperature during the year because of the influence the water temperature on the growth rate. During the months of the year with the highest temperatures, the growth of the fish was more rapid. Considering the hypothesis that fish growth does not have a similar behaviour, needs of fishes might change according to their growth stage. Aside of temperature influence, specific feeding rate might affect the growth rate and consequently the feed conversion rate. Underfeed the fish in rearing conditions might provokes many problems, like cannibalism, which lead to difficulty to estimate stocking density. These constraints will lead generally to bad control of feeding strategy.

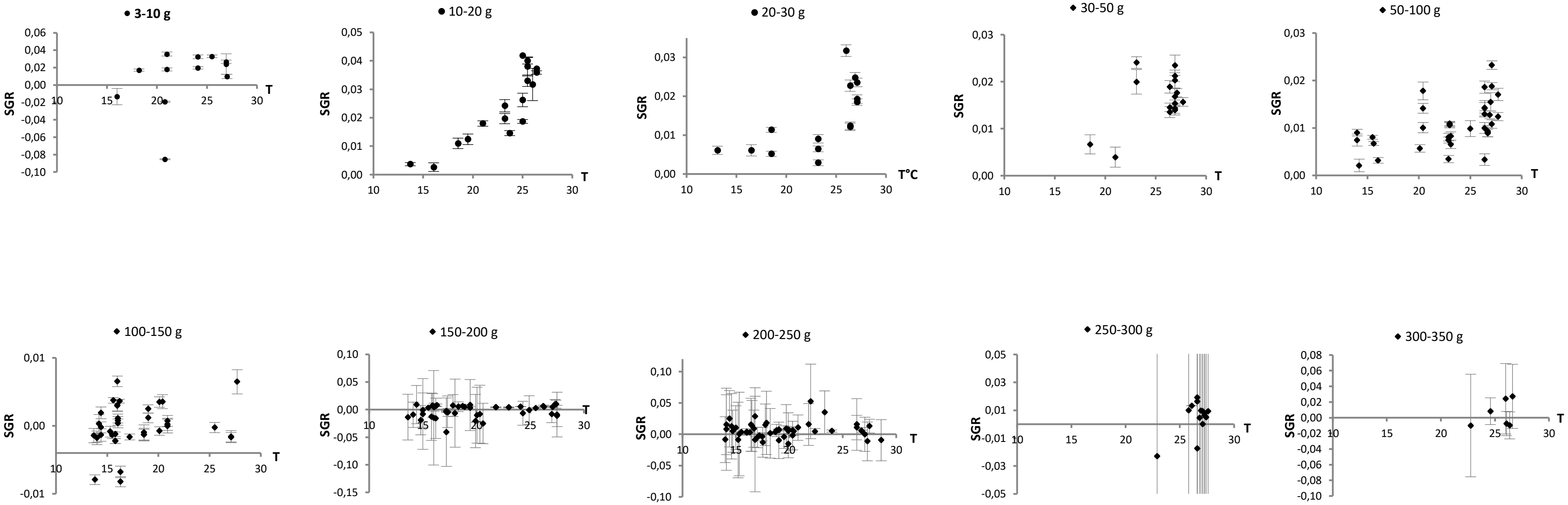


Figure 3.10: Relationship between SGR (g.day^{-1}) and water Temperature (°C) at different classes of weight of fish

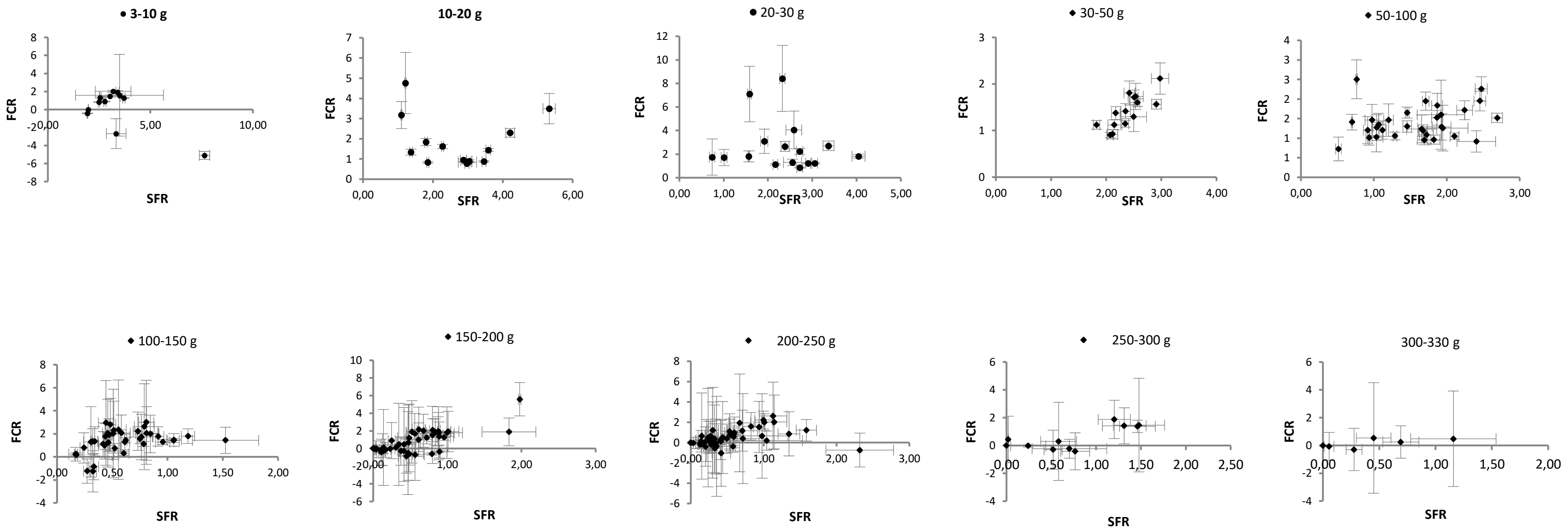


Figure 3.11: Relationships between FCR (%) and SFR (%.g [feed]/(g[BM]) at different classes of weight of fish

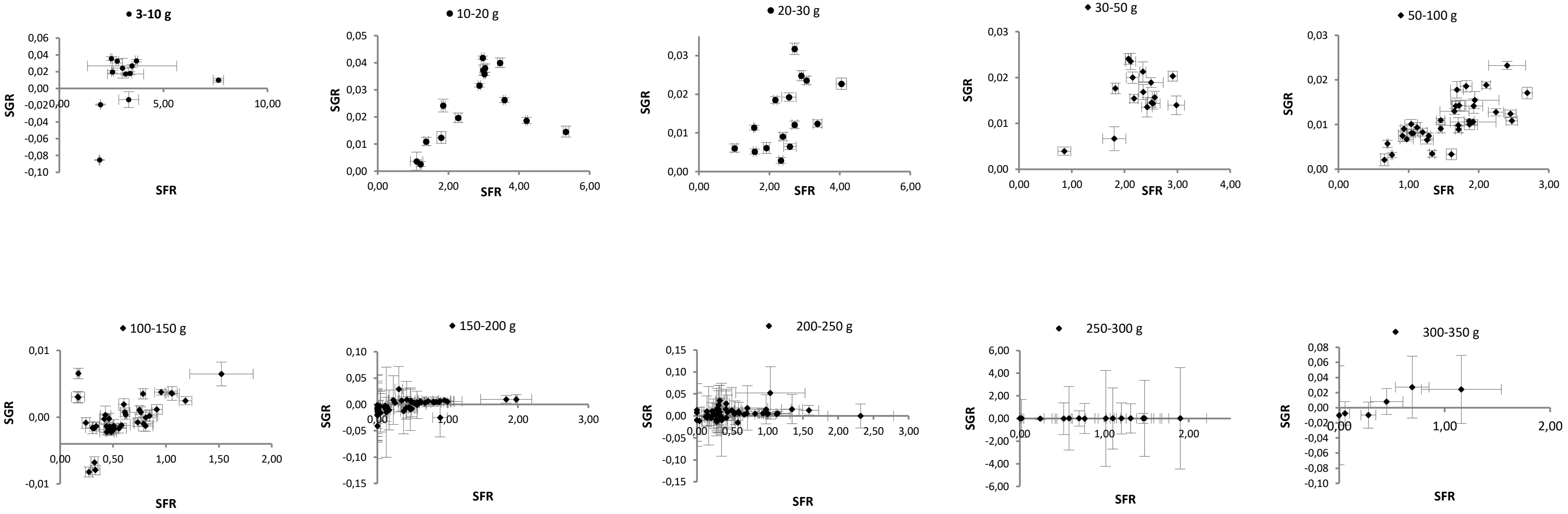


Figure 3.12: Relationships between SGR (g.day^{-1}) and SFR (%.g [feed]/(g[BM]) at different classes of weight of fish

PCA analysis of the whole data set of 21 cages (weight of fish, Temperature, SFR, SGR and FCR) provided good correlation, highly significant between SGR and SFR, and a negative correlation between SFR and weight of the fish (Table 3.5).

Table 3.4: Correlation matrix

		Z Score (SGR)	Z Score (SFR)	Z Score (FCR)	Z Score (T)	Z Score (w)
Correlation	Z Score (SGR)	1,000	,591	-,282	,305	-,411
	Z Score (SFR)	,591	1,000	,057	,419	-,623
	Z Score (FCR)	-,282	,057	1,000	-,048	,042
	Z Score (T)	,305	,419	-,048	1,000	-,004
	Z Score (w)	-,411	-,623	,042	-,004	1,000
Signification (unilateral)	Z Score (SGR)		,000	,000	,000	,000
	Z Score (SFR)	,000		,160	,000	,000
	Z Score (FCR)	,000	,160		,200	,231
	Z Score (T)	,000	,000	,200		,473
	Z Score (w)	,000	,000	,231	,473	

Table 3.6. showed that the first principal component was strongly correlated with four of the original variables. The first principal component increased with the increase of SFR, SGR, and temperature and the decrease of weight This suggested that these four criteria vary together, if one increased, then the remaining ones tended to increase as well, except the weight, which tended to decrease. This component can be viewed as a measure of the quality of SFR, SGR, weight, and temperature, and the lack of quality in FCR, which can be explained by the fact that SFR and SGR reached high value at high temperature condition and for the smallest fish weight and consequently will record a very low FCR.

Table 3.5: PCA component loadings of variables measured in seabream production

	Component	
	1	2
Z Score (SFR)	,894	,272
Z Score (SGR)	,815	-,259
Z Score (weight)	-,715	-,266
Z Score (T)	,503	-,100
Z Score (FCR)	-,185	,931

Furthermore, we see that the first principal component correlated most strongly with SFR. In fact, we could state that based on the correlation of 0.894 that this principal component is primarily a measure of SFR. The second principal component increases with only one of the values, increasing FCR. This component can be viewed as a measure of efficiency of the productivity of the fish farm.

The FCR defined, as ratio between total amount of feed consumed and the biomass gain, determine the performance of the growth and the economic profits. Fishes is performing, if most food amount eaten is attributed to growth and food wastage is minimal (Klaoudatos and Conides, 1996), expressed also as scope for growth expressed as the minimum difference between food amount eaten and food attributed to growth.

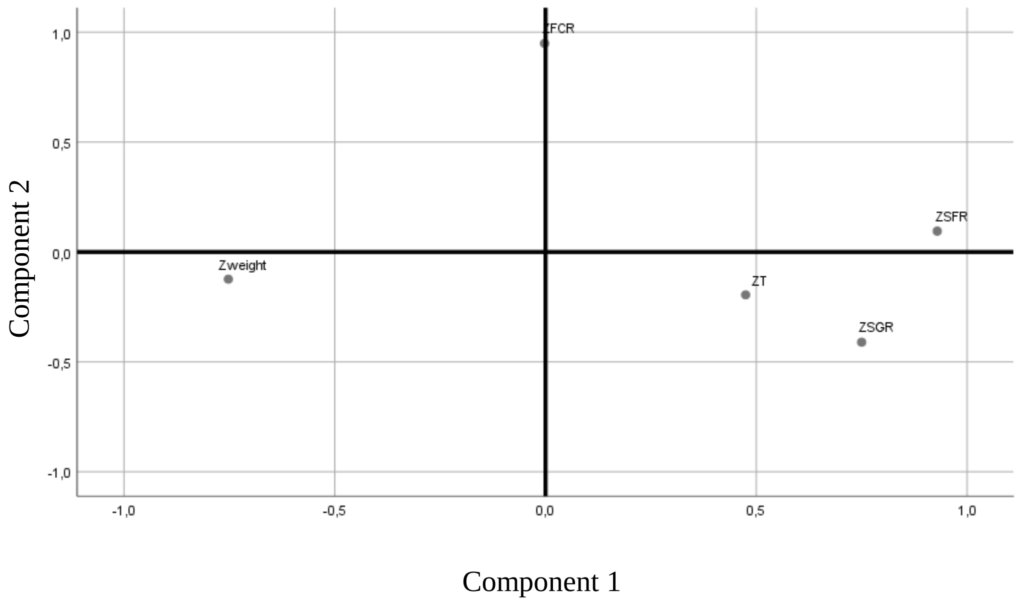


Figure 3.13: Principal component analysis (PCA) plot of weight, temperature, SFR, SGR and FCR from gilthead sea bream.

Component 1 (45%) and component 2 (23%) represent the first and second principal components, with the percentage of explained variance, as indicated in parentheses. Component 1 provided the greatest discrimination, accounting for almost the half of total data variability.

The variables with the highest load on the first component were related mainly to the husbandry rate SFR, the functional trait SGR, the temperature and weight. FCR was highly load on the second factor.

According to Stauffer (1973), three are the major independent variables involved in growth: ration size, fish weight, and the water temperature.

Accordingly, one of the most frequently studied environmental factors is water temperature, viewed by several authorities as the most important environmental influence on growth and the feed conversion rate (Hernandez et al. 2007; Brett 1979). Moreover, knowledge of the optimum feeding rate is important to secure the growth and promote environmental conditions. These three factors can be deterministic for the profitability of the production.

PCA analysis, was a good statistical analysis giving a direction of parameter or function traits that should be considered for creating a growth model for sea bream, at such fish farm status and for a better mastery of production boundaries.

3.4 Conclusion

The results of the statistic and descriptive analysis showed that there were many factors, that can influence the growth and affect the time required for the fish to reach the desired commercial size, which are mainly the functional traits reflecting the potential of fishes to grow, the husbandry trait defining the feeding strategy and the temperature, as the most important environmental factor.

Monitoring of selected cages demonstrated a certain dependency of the growth of the sea bream, on water temperature fluctuations, as the most interesting weight gain was recorded at the optimal water temperature of growth for sea bream. The optimal growth rate was recorded at the highest temperature and which correspond also to the highest value of the specific feeding rate. The feed intake had a tendency to increase and the growth rate as well, simultaneously, during the high season to get reduced progressively through winter time. Depending on temperature seasonality, avoid the excess of feeding, is one of the primary tasks. On the other side, underfeeding the fish should not be neglected as the competition for the feed can induce a big variation on the size of the fish. This heterogeneity arouses cannibalism inside the cage, which might induce uncertainty and overestimation of the biomass and consequently the quantity of feed to distribute, which will steer again to excess of feeding. This phenomenon is very well known by the fish farmers but not enough studied by the scientific research.

Mc Carthy et al. (1992) demonstrate that decrease in feed supply for the trout induce an increase on the variation coefficient of fish weight; Jobling et Koskela (1996) observed the same on rainbow trout. According to these two authors, food restriction impacts and intensifies competitiveness, which must be avoided in fish farms, to prevent biological and economic losses.

CHAPTER 4

ASSESSMENT OF GROWTH MODEL BASED ON THE THERMAL GROWTH COEFFICIENT FOR GILTHEAD SEA BREAM (*Sparus aurata*) FARMED IN MARINE CAGES UNDER REAL PRODUCTION CONDITIONS, IN TUNISIA

4.1Introduction

In sea cage farming, fish are exposed to seasonal variations of water temperature, and these variations can differ from one location to another. A small increase in water temperature does not only stimulate growth of the fish but also lowers dissolved oxygen concentration in water. Dissolved oxygen may then become a rearing constraint during the production cycle if the oxygen requirement of fish is higher than the supply. The impact of this constraint on production parameters, specially stocking density of and thus, on economic profit of a farm will depend on both local thermal regime and growth potential of the fish. Increased growth is one of the most important traits in a breeding objective to increase production capacity and profitability (Besson and al, 2016).

Growth models are a basic tool used in aquaculture, to predict and master the growth and profitability of fish farms. Most of the classic models were based on the assumption that growth depends on live weight affected by the exponent 2/3, based on the metabolic growth model developed early last century (Bertalanffy, 1938, 1957; Mayer et al, 2008). An alternative is to use the “thermal unit growth coefficient (TGC)” model developed by Cho and Bureau (1998) and Dumas et al. (2007) in growing trout, and Mayer et al. (2008, 2009) in gilthead sea bream. This model is a particular version of the von Bertalanffy equation that incorporates a cumulative water temperature, which allows an estimation of fish growth in several temperature conditions, constituting an interesting tool for aquaculture management. In the case of gilthead sea bream, growth patterns were considered as a function of the cumulative effective temperature Σ (T_i-12), because growth is zero, or negative, for water temperature below 12°C (Mayer et al., 2008, 2009). Other models have also considered the average temperature (Lupatsch and Kissil, 1998; Lupatsch et al., 2003; Petridis and Rogdakis, 1996) but their practical application was difficult. In a previous paper Mayer et al. (2008) studied various growth models for the gilthead sea bream considering the variability of water temperature. One of the key findings of the paper was that the best models, including the TGC model, were those that considered the accumulated effective temperature as an independent variable, instead of the time.

The aim of the work was to develop a new approach to assess the growth of gilthead sea bream under commercial production conditions in the south part of the Mediterranean Sea, with great fluctuations in the water temperature and considering the different stages throughout the growth period, in order to improve the estimation of growth on aquaculture farms in Tunisia.

Fish farming of sea bream, *Sparus aurata* and sea bass, *Dicentrarchus labrax,* in open sea, had started in Tunisia only on 2008 and the mastery of the growth along the whole cycle of production remain the key of success and profitability of this sector. Knowledge about the evolution of weight distribution over a period of time may be an essential tool to explain how fish are growing, but no published model considers it, in Tunisia. This knowledge can provide more complete information about growth compared with simple mathematical growth models, and help to decide when to perform size classifications, separating two or more sizes that are smaller or larger than the average, to control the feeding strategy and to determine the right time for harvesting. Our initial goal was to detect the existence of significant changes in the dynamics of the evolution of the average weight of fish over a complete cycle of production by using TGC model and to compare it to the real growth recorded at the same temperature parameters.

4.2 Materials and methods

4.2.1 Data description

Weight data from 21 batches of sea bream (Table 4.1), growing in a marine fish farm located in the southern Mediterranean were considered for the current study. Each cage contained around 300.000-350.000 fish, with an initial weight comprised from 3.2 to 49 g and the final weights varied from 169.9 to 370.9 g. The mean value of the final density was in the range of 15 kg m^3. Sea bream were fed, 7 days per week, one or two times per day with commercial diets. Water temperature was recorded every day and varied from a lowest of 14.2 °C in February, to the highest of 27.3 °C in August. Throughout the period from 2010 to 2016, minimum 100 fish from each cage were weighed every 30-60 days, I calculated the average weight to be used to test previous models produced by Rogdakis 1996; Lupatsch and Kissil 1998; Lupatsch et al. 2003 and reused by Mayer et al, (2008, 2009, 2012).

The work followed considering three steps: In the first step, I computed the cumulative effective temperature for each cage, according to the daily temperature recorded at study site.

In second place, I used the model defined by Mayer et al., 2012, to simulate the growth of the 21 batches and to compare it, at third step to the real growth, in order to distinguish limited constraints faced at the studied fish farm.

4.2.2 Mathematical models

The temperature function T(t) depends on the context, in the case of marine farms in fixed locations, fish live in an environment where the water temperature evolves according to regular annual cycles. A simple one-year periodic expression, which allows to include the seasonal influence of temperature on growth in the model, is based on the sinusoidal function used in different studies. Equation 4.1, defined by Mayer et al (2012), was used to represent the temperature sinusoidal function according to time by using the daily temperature measured at the area of the fish farm, to evaluate the thermal seasonal cycle.

$$T(t) = T_m + T_D \,.\sin(\frac{2\pi}{365}\,(t-\alpha)) \tag{4.1}$$

where $t \geq 0$, and Tm is the average annual temperature, TD is the amplitude and α is a tuning parameter. From Eq. (4.1), we obtain a compact expression for the cumulative temperature function in the time interval [t_0, t].

In the case of gilthead sea bream, it is more appropriate to use the effective temperature, T(°C) -12, instead of T(t) (Mayer et al., 2008), which only involves replacing Tm by Tm -12. In Equation (4.2), it’s represented the formula of the cumulative effective temperature ST.

$$ST(t_0,t) = (T_m - 12)(t_0 - t) - T_D\,\frac{2\pi}{365}\,(\cos\,(\frac{2\pi(t-\alpha)}{365}) - \cos(\frac{2\pi(t_0-\alpha)}{365})) \tag{4.2}$$

Two models were developed to simulate the seasonal indeterminate growth of gilthead sea bream. Both models were obtained by fitting the data into Equation (4.3), assuming the values of b=1/3 and b=2/3, based on actual values of accumulated temperature, recorded at the farm for the correspondent year. A preliminary exploratory analysis of the data from the 21 batches was performed, considering the discrete model in Equation (4.3):

$$W_f = (\,W_0^b + TGC_b.ST)^{1/b} \tag{4.3}$$

where parameters b and TGC_b, were estimated by Mayer et al, (2012) by the Levenberg–Marquard iterative method available in Statgraphics© plus version 5.1. The exploratory analysis studying the model (4.3) with both b=1/3 and b=2/3 was using a least square fit after linearization. Mayer et al (2012) obtained, by the way, the values for TGC, named $TGC_{1/3}$ and $TGC_{2/3}$, equal to 0.00164561 and 0.0160949 respectively.

TGC, thermal growth coefficient, was computed using the following equation (4.4):

$$TGC = \frac{W_f^{1/3} - W_I^{1/3}}{ST} \tag{4.4}$$

In addition to the simulation of the growth based on the TGC models, computation of the feed conversion rate FCR, and the biological conversion rate BCR, both defined in the chapter 3 section 3.2.3, were done for the 21 cages based on the real weight and the weight simulated by the two models. To calculate the FCR and BCR for the two models, estimation of the total feed needed for the growth modelled, was done based on the feeding table of the feed supplier and according to the weight reached at the given time and the corresponding water temperature. BCR was computed to be able to distinguish the effect of the mortality on the variation of the FCR, knowing that BCR, at the opposite of the FCR, take on consideration the biomass of mortality. The mortality can occur after mishandling of net during the change, diseases or transportation. In general, mortality does not have a direct link with the feeding strategy. The goal was to compare the strategy followed by the farmers, which did not obey to suppliers' feeding rates, in order to compare the FCR that the farmers obtained with respect to what would have been obtained, ideally, following the feed supplier's table.

4.3 Results and discussion

Table 4.1 provides data on ranges of practical information that serve to understand the status of fish and to present the basis data used for growth model simulations. Differences in farmed practices among the same fish species grown within the farm can have subtle differences in modelling outcomes, as the initial weight, duration of the production cycle, temperature, and ST, which is related to the duration and the starting of the cycle, were different. As models integrate small changes and can provide overall mass balance estimates, they were able to generate a completely different modelled growth, from case to case.

Considering the average value, sea bream grew from 9.7 g to 238.1 g, in 495 days equivalent to ST = 4520.9 °C and an average temperature of 21.1 °C.

Average growth rate expressed as the specific growth rate SGR, defined in the previous chapter, section 3.2.3, was equal to 0.0176, as mean value and TGC was ranged at 0.0073, with end point 0.0055 and 0.0092.

Two seasonal models were established based on Eq. (4.3) to describe the growth of gilthead sea bream: the seasonal 1/3-TGC model and the seasonal 2/3-TGC model.

Several simulations of growth were made using the equation (4.1) obtained as mentioned above. The TGC model was run for the whole cycle from the pre-growing to the on growing for 21 cages.

Figure 4.1 represented the temperature function, the ST data over a period of time and the weight as function of ST for batch 3-2015. At a first stage (<100g), the real weight and the modelled growth of model 1 were superimposed. At a second stage (>100 g), the real weight was below the simulated weights of both models, but the shape of the growth was following model 2. A smooth transition from the dynamic of the growth described by the model 1 and 2 demonstrated that the real growth can be represented by a mixed model, combining both models.

Figure 4.2 shows the real weight (black line) together with the estimated weight curves obtained from the two models, 1/3-TGC (Green line), 2/3-TGC (Blue line) for the six batches, represented in blue in table 4.1, to compare the real growth to the simulated ones, generated at the same period and same temperature conditions. As a general observation, confirmed also by the data presented on table 4.2, final weights simulated by model 1 and 2 were very high compared to the real weight reached for the 21 cages. At the beginning of the production cycle, during the interval of time between 100 and 200 days, the real growth and the simulated growth generated by model 1, specifically, were overlapped and then diverged to lead to a high gap between the real weight and the modelled, at the end of the cycle of production.

It was also concluded that the 1/3 TGC of model 1, gives better results for the estimated weight of fish in early stages. Mayer et al, (2012), distinguished two stages of the growth: the case in which the real final weight is less than 117 g (first stage) from the case in which the real initial weight is greater than or equal to 117 g (second stage). Growth curves, representing the real weight showed two different shape of growth. At a first stage, the real growth match very well with the growth simulated by model 1. In average the fish weight was between 100-150g, before to diverge and decrease considerably compared to the modelled growth.

Table 4.1: Description data of the real growth of 21 cages of sea bream, farmed in marine cages under commercial production conditions

Batch	Samples along the period	Period (Days)	Initial weight W0 (g)	Final weight Wf (g)	T(°C)	ST(°C)	TGC ($g^{1/3}$°C-^{1})	SGR (%d^{-1})
1-2010	27	301	21,8	205,3	20,3	2 505,4	0,0075	0,0244
2-2010	27	206	49,0	237,1	22,3	2 139,7	0,0077	0,0293
3-2010	19	235	27,4	215,4	21,3	2 207,6	0,0088	0,0284
4-2010	40	491	4,8	192,6	20,4	4 151,1	0,0075	0,0151
1-2011	25	507	10,3	173,3	19,9	4 034,4	0,0056	0,0135
1-2012	21	534	3,4	276,6	21,4	5 059,5	0,0082	0,0180
2-2012	20	506	3,8	268,2	22,0	5 074,3	0,0084	0,0174
3-2012	24	500	4,3	312,0	22,0	4 993,7	0,0086	0,0205
1-2013	16	476	13,6	190,3	19,4	3 536,6	0,0055	0,0161
2-2013	16	433	11,3	195,6	20,1	3 521,8	0,0066	0,0171
3-2013	14	401	9,0	184,0	20,1	3 289,9	0,0075	0,0176
4-2013	21	480	8,9	207,2	21,5	4 589,6	0,0066	0,0144
5-2013	17	497	5,5	204,1	21,7	4 852,4	0,0073	0,0136
6-2013	18	448	4,9	169,9	21,1	4 101,6	0,0079	0,0134
1-2014	31	726	4,9	288,0	20,9	6 476,4	0,0056	0,0146
2-2014	26	719	2,9	221,0	20,9	6 433,7	0,0060	0,0113
3-2014	26	686	3,2	247,0	20,6	5 911,5	0,0063	0,0138
4-2014	26	689	3,7	261,2	20,6	5 947,1	0,0062	0,0144
1-2015	24	478	3,3	270,3	22,1	4 859,6	0,0092	0,0183
2-2015	28	527	3,8	310,4	22,4	5 504,5	0,0083	0,0178
3-2015	14	553	3,2	370,9	22,3	5 749,0	0,0086	0,0213

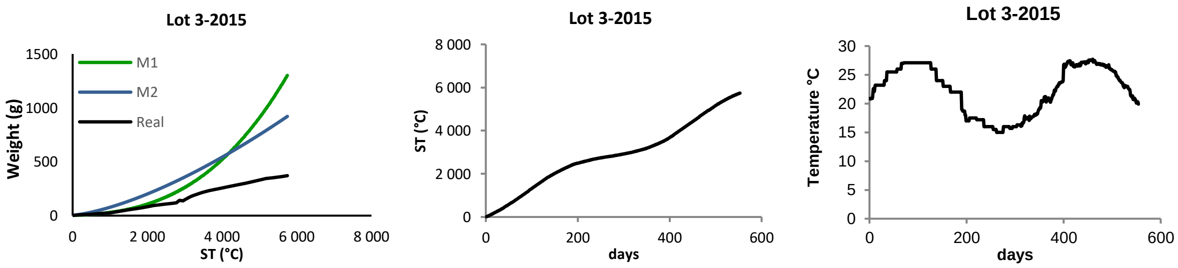


Figure 4.1: Curves representing the instantaneous growth according to ST and the seasonal fluctuation of the temperature and ST, according to time

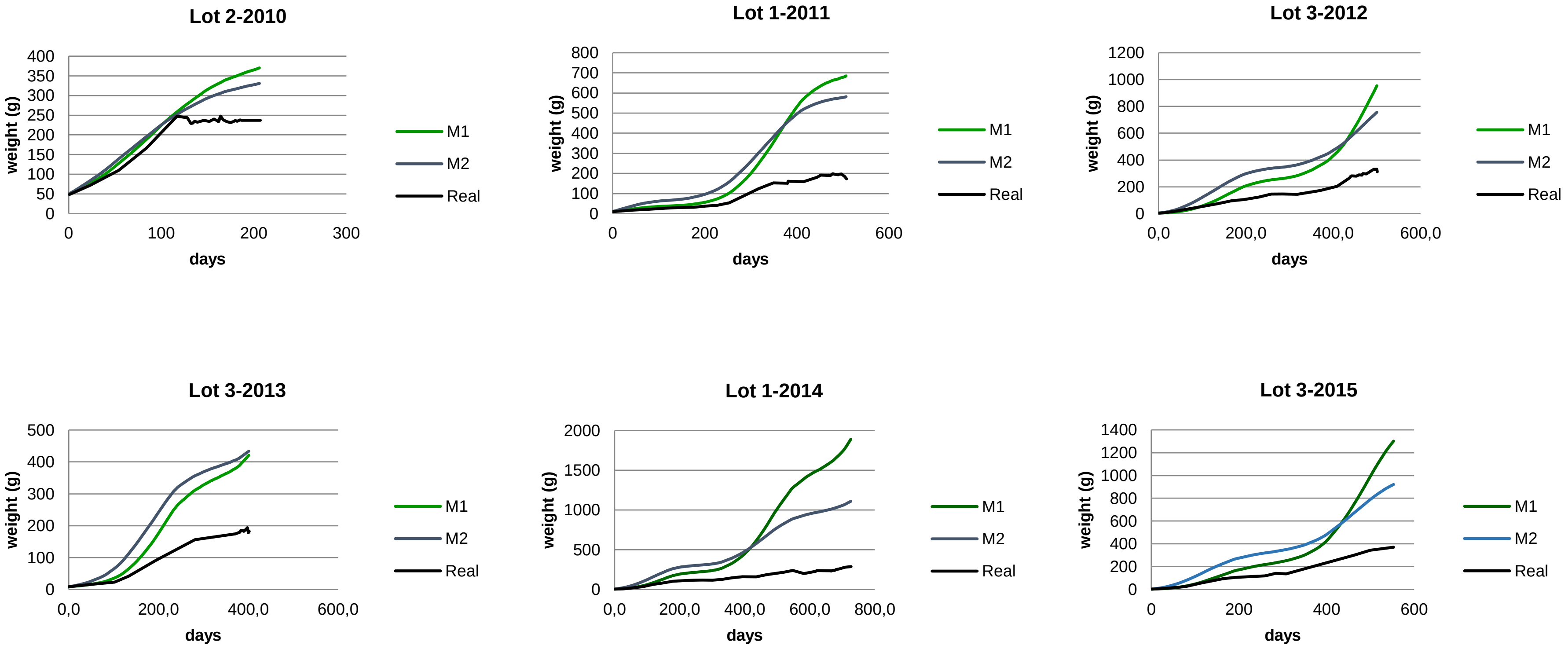


Figure 4.2: Growth curves generated with two models (1/3-TGC and 2/3-TGC) and real data from six batches selected as an example from 21 batches

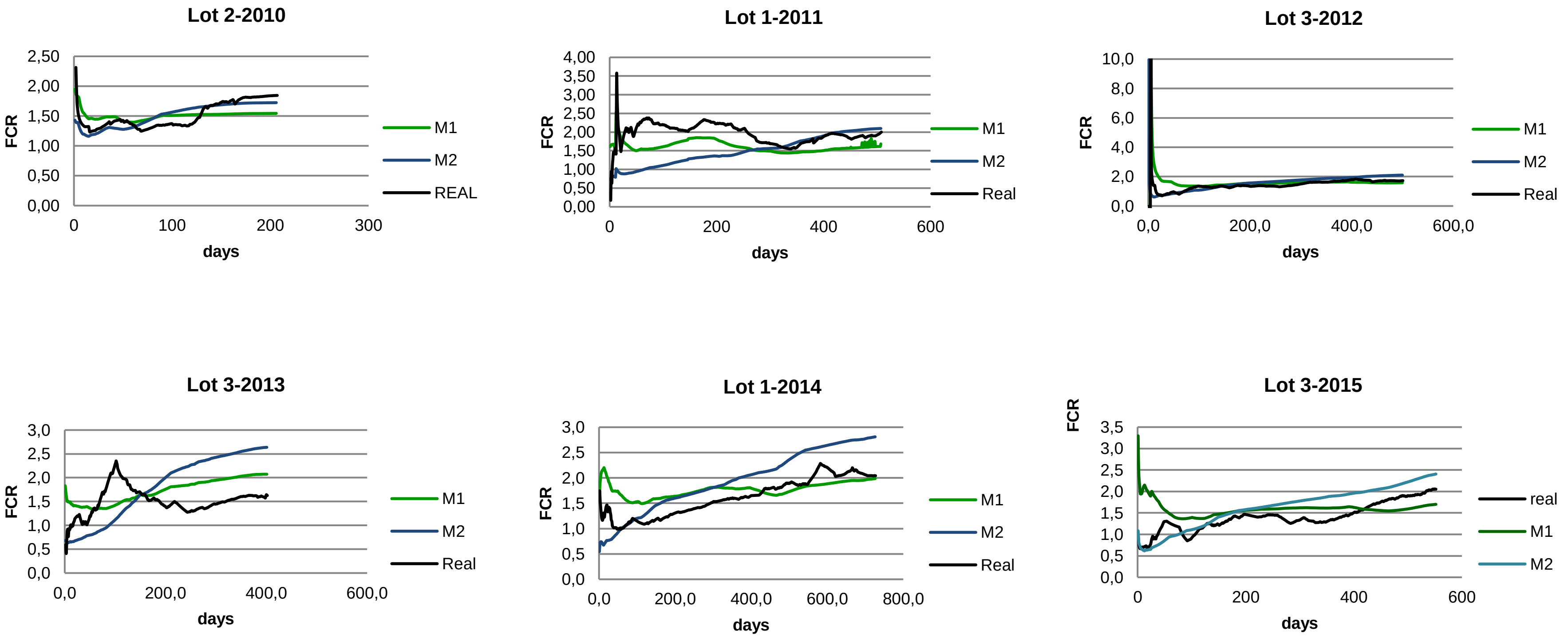


Figure 4.3: Feed conversion rate curves (FCR), obtained by model 1 and 2 and compared with the real FCR

Figure 4.2 and 4.3 displayed the growth and the feed conversion rate, defined as feed required to produce a unit of fish body mass, used to assess the real growth compared to the modelled simulation. For batch 2.2010, fish weighted 245 g with FCR equal to 1.4, while for the modelled growth, the FCR recorded, at 110-112 days, was 1.5 and 1.6 respectively for model 1 and 2. One month later, growth was affected by the decrease of temperature and FCR increased considerably reaching 1,8 for the same weight. The growth of fish remained optimal at a first stage. For batch 1.2011, the final weight was 192 g with FCR equal to 2.0, reached in 17 months while the FCR of model 1 and 2 was equal to 1.5 for the same weight reached in 9-10 months. Fish were underfed, as the cumulative quantity distributed represented only 55 % of theoretical quantity and 31% and 29 % of the quantities of feed calculated for model 1 and 2, respectively. In the case of batch 3.2012, at the first 7 days, the mortality reached 12.6 %, which provoked a punctual increase on FCR to 1.78, while BCR remained at 0.9. Real FCR decreased progressively to 1.3 in 100 days. The growth of the fish concorded with the simulated growth of model 1, reaching respectively 57.7 g and 53.9 g. The cumulative feed also was equal to quantity calculated for model 1 and representing 85 % of the theoretical quantity. The interruption and the limited quantity of feed distributed and the decrease of temperature, all these factors affected negatively the growth. After almost 17 months, a final weight of 312 g and 1.73 of FCR were recorded, while FCR of model 1 and 2 was equal to 1.6 reached on 11.5 and 7 months. For batch 3.2013, as most of the batches, fish were undernourished, compared to the theoretical quantity of feed, as the real quantity represented only 42 % and 33 % of the feed quantity of models. The gap between the total quantity of feed consumed and the cumulative feed computed for the two models was evident during the high season, when temperature started to increase. The growth was not affected and remained optimal, compared to the modelled growth. In 24 months, fish of batch 1.2014 reached a final weight of 288 g with FCR equal to 2.0 and fish were underfed by 61 % compared to the theoretical quantity and by 84.5% compared to total feed needed for the two models.

For 3.2015, the growth was optimal at the beginning of the cycle to slow down after 5 months and to reach by the end of the cycle 370 g with FCR equal to 2.1, while the FCR of model 1 and 2 recorded only 1.6 and 1.8 respectively. The limited growth was the consequence of limited quantity of feed compared to the theoretical quantity and the quantity of feed for the models. The simulated weights reached, in 553 days, 1301 g and 920 g respectively for model 1 and 2.

Table 4.2: Final weight, Final FCR and final BCR reached at real condition and by using model 1 and 2 (b=1/3 and b=2/3) considering daily temperature conditions

Batch	Real Final weight Wf (g)	Model 1 Final weight Wf (g)	Model 2 Final weight Wf (g)	Real FCR	FCR Model 1	FCR Model 2	Real BCR	BCR Model 1	BCR Model 2
1-2010	205,3	331,1	334,0	2,02	1,62	1,74	2,02	1,61	1,73
2-2010	237,1	370,2	330,8	1,85	1,54	1,72	1,85	1,69	1,72
3-2010	215,4	293,8	298,1	2,15	1,78	1,90	1,89	1,58	1,68
4-2010	192,6	617,6	581,3	2,32	1,54	1,91	2,32	1,54	1,91
1-2011	173,3	684,9	581,5	2,00	1,68	2,10	1,91	1,62	2,01
1-2012	276,6	951,5	765,9	3,86	2,88	3,99	1,94	1,61	1,98
2-2012	268,2	973,5	771,3	4,66	3,40	5,36	1,81	1,58	1,94
3-2012	312,0	953,9	756,4	1,73	1,58	2,10	1,73	1,58	2,10
1-2013	190,3	544,3	493,9	2,19	2,27	2,90	2,10	2,20	2,80
2-2013	195,6	519,0	484,7	2,14	2,11	2,72	2,08	2,08	2,66
3-2013	184,0	420,6	433,4	1,63	2,07	2,64	1,57	2,01	2,54
4-2013	207,2	890,8	690,9	2,08	1,60	2,19	2,05	1,59	2,16
5-2013	204,1	926,7	731,9	2,01	2,11	3,05	2,00	2,11	3,04
6-2013	169,9	603,5	572,0	1,99	2,10	2,87	1,98	2,09	2,87
1-2014	288,0	1888,5	1108,9	2,04	1,99	2,81	1,95	1,93	2,70
2-2014	221,0	1735,2	1085,1	2,07	1,96	2,85	1,97	1,90	2,72
3-2014	247,0	1405,0	960,0	2,00	1,85	2,64	1,89	1,77	2,50
4-2014	261,2	1455,7	971,8	1,94	1,87	2,64	1,80	1,77	2,47
1-2015	270,3	853,5	721,3	1,90	1,56	2,06	1,89	1,56	2,06
2-2015	310,4	1189,0	865,7	1,90	1,62	2,23	1,90	1,62	2,23
3-2015	370,9	1301,1	920,8	2,05	1,70	2,41	2,04	1,69	2,39

As said before, Mayer et al (2012) concluded that for the two models, 1/3-TGC and 2/3-TGC a change in the pattern of growth for gilthead sea bream under commercial production conditions was noted, as the presence of a transition weight value from around 117 g was detected, which indicates a turning point for the dynamics of growth in the weight of fish. The hypothetical physiological process of change that occurs at 117 g was not explained. The results indicate the need to address a more detailed study of allometric growth of gilthead sea bream under production conditions.

Nevertheless, the reasons for the change in the pattern of growth should be related with aspects such as compensatory growth, genetic potential, allometric growth, nutrients or physiology of reproduction.

The same author demonstrated that the hypothesis tests considering the resulting variable by subtracting the actual weight minus the estimated weight, D=Wreal−West.

The sign of the difference between the real and the estimated weights, determine if a model overestimates or underestimates the real weight.

To consider this hypothesis in the present case, an assessment of the feeding strategy was conducted for the 21 cages to better understand the effect of the technical management in the final growth. Table 4.3 demonstrated the total amount of feed needed for model 1 and 2 compared to the theoretical total quantity and the total feed really consumed by the fish.

Table 4.3: Cumulative feed calculated for model 1 and 2, compared with the theoretical amount of feed and the real quantity distributed per fish

Batch	Total quantity of feed consumed per fish (g)	Total theoretical feed per fish (g)	Total feed per fish (g) Model 1	Total feed per fish (g) Model 2	Ratio between real and theoretical quantities
1-2010	487,4	426,2	502,5	563,1	1,1
2-2010	423,5	443,7	511,4	508,2	1,0
3-2010	375,5	410,1	430,3	469,5	0,9
4-2010	491,4	748,9	959,0	1161,3	0,7
1-2011	341,3	618,4	1067,2	1169,3	0,6
1-2012	515,8	793,9	1516,7	1686,0	0,6
2-2012	543,1	762,2	1557,3	1712,2	0,7
3-2012	549,3	954,6	1516,9	1656,4	0,6
1-2013	374,8	495,6	859,4	958,8	0,8
2-2013	392,1	487,4	818,4	1000,5	0,8
3-2013	278,4	454,0	657,7	821,1	0,6
4-2013	408,5	408,5	1411,9	1508,2	1,0
5-2013	412,3	755,8	1460,8	1575,3	0,5
6-2013	363,7	612,4	959,9	1163,1	0,6
1-2014	531,6	1358,7	3777,7	3127,0	0,4
2-2014	436,6	1131,9	3328,3	2991,7	0,4
3-2014	466,6	1012,6	2524,9	2461,4	0,5
4-2014	443,1	443,1	2665,2	2569,0	1,0
1-2015	558,6	824,1	1327,9	1538,6	0,7
2-2015	620,4	1063,4	1984,4	2026,2	0,6
3-2015	767,4	1257,5	2214,1	2231,0	0,6

The ratio between the real and the theoretical quantity of feed demonstrated the fact that the farmers did not obey to the recommendation of the feed supplier’s.

An average, the total quantity of feed consumed by fish, for the 21 cages represented 465.8 g, which represent 69 % of the theoretical quantity recommended by the feed producers and 41 % and 37 % of the quantity of feed computed for model 1 and 2, respectively.

Simulation (Figure 4.4) carried out using the above-mentioned growth model (Eq 4.3 of Mayer et al., 2012) and the computation of needed feed of the manufacturer's recommendations leading to the cumulative feed presented in Table 4.3, demonstrated for instance for batch 3-2012 the following: 549.3 g of feed was supplied for one fish to increase its weight from 4.3 g to 312 g, in 500 days, equivalent to feed conversion rate (FCR) equal to 1.73, for the whole on-growing process. While the theoretical corresponding quantity of feed computed was 954.6 g and the quantity for model 1 and 2 were 1516.9 g and 1656.4 g, respectively. These demonstrate that in the major cases and at the end of the on-growing cycle, fish were underfed, which affect the growth speed and the gap between the final real weight and the modelled ones.

When feeding, fish go through different sequential phases, including stimulation, identification-localization and consumption. The last involves food intake and ingestion or rejection (Lamb, 2001). Simulations under Mediterranean fish farming conditions up to a final body weight of 500 g reveal that losses by chewing may reach 8.45% of the supplied food on average using the pellet sizes recommended by the aquafeed producer. Rearing larger fish would involve even higher levels of feed waste (Ballester-Molto et al., 2016).

Controlling feed ration is often considered (Cacho et al., 1991; Mistiaen and Strand, 1999; Hernandez et al., 2007), mainly because the cost of feed is a large fraction of the overall rearing costs.

Stocking and harvesting decisions are very important, sometimes than the factors, which affect directly the growth rate (Hernandez et al., 2007). These decisions are strongly affected by the price system, specifically feed cost, investment cost and the revenue from selling the fish.

Hence the fish past history (such as periods of under-feeding) has no effect on its current response to the environment. The ration correction, has been considered extensively in the literature, and is mostly described as a diminishing-returns or concave curve (Brett, 1979, Jobling, 1994), and sometimes by a Monod equation (Jobling, 1994). The curve is nearly linear for low rations and has a negative growth intercept defining the maintenance (zero growth) ration. The ration function is sometimes used to define the ‘optimal’ ration in terms of the level where the feed conversion rate, FCR is minimal (Brett, 1979; Corey et al., 1983; Jobling, 1994).

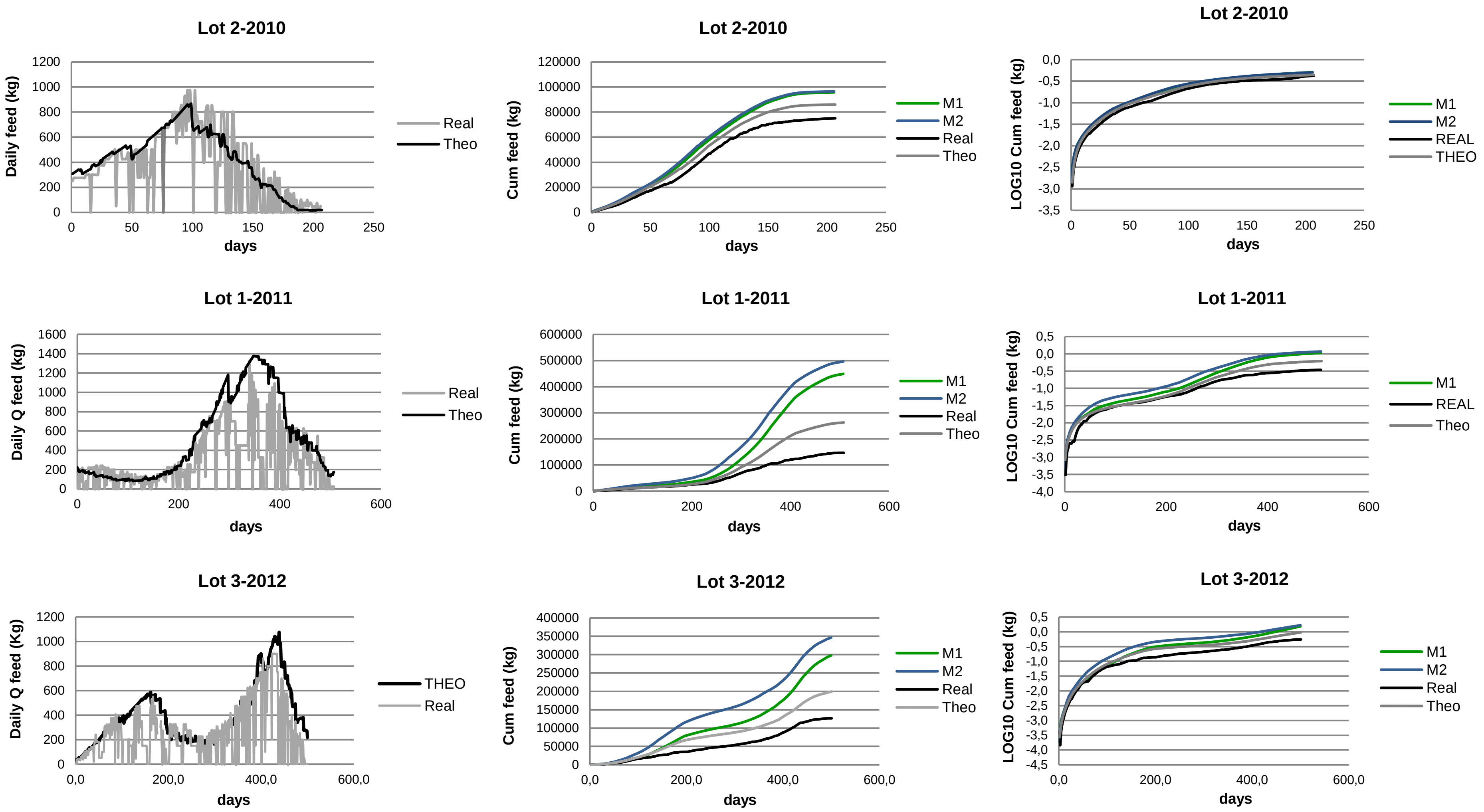


Figure 4.4: In first column the daily amount of feed distributed per cage compared to the daily theoretical quantity, the second the cumulative feed really consumed, the theoretical and the feed computed for the models and the third column the logarithm of the cumulative feed (Generation 2010, 2011 and 2012)

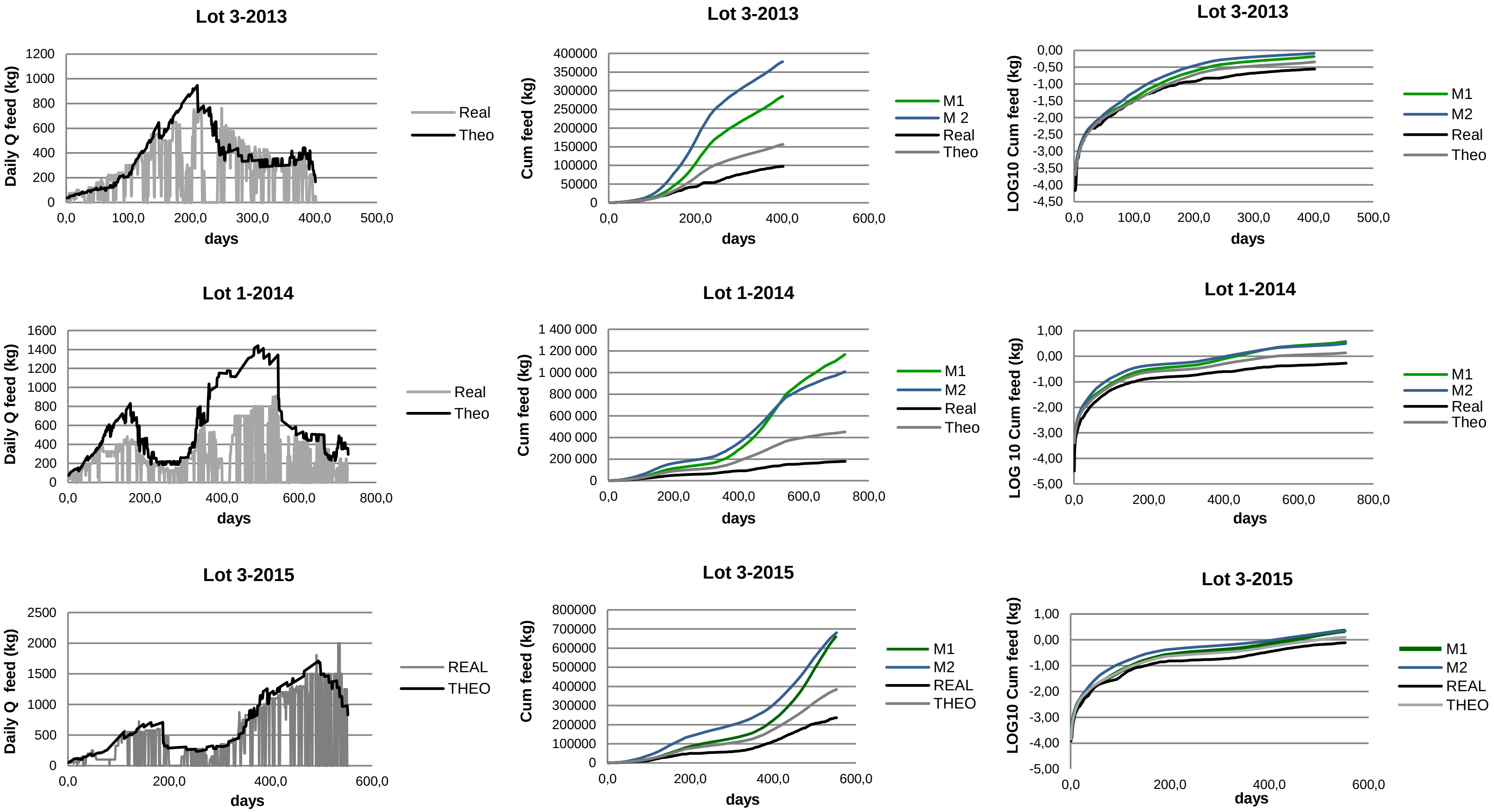


Figure 4.5: In first column the daily amount of feed distributed per cage compared to the theoretical, the second the cumulative feed really consumed, the theoretical and the feed computed for the models and the third column the logarithm of the cumulative feed (generation 2013 ,2014, 2015)

Curves of figure 4.4 and 4.5 demonstrated the variation on the feeding strategy inside the fish farms of gilthead sea bream from year to year. In general, for all cages, the total feed consumed per cage was under the theoretical quantity and the quantity calculated for models, except the generation of 2010, where the fish were fed at 95 % of theoretical quantity and 82-83% of the quantities simulated by models 1 and 2.

The daily quantity of feed distributed showed the gap between the real and the theoretical daily feed quantity. During many days, the real quantity of feed was equal to zero because of the storms. It’s important to mention that the area of the fish farm studied was very exposed, and these might be a constraint for the growth.

The cumulative feed and the logarithm function demonstrated that the divergence of the real quantity compared to the quantity of feed of model 1 and 2 occurred after the first 100 days of the on-growing cycle, which coincides with earlier stages explained by Mayer et al, (2012), as physiological process of change arisen at early stage of the rearing cycle of sea bream.

The plot of FCR of the 21 cages (Figure 4.6), as function of the ratio between the feed consumed and the theoretical quantity demonstrated that for ratio ranging around 0.6, the FCR varied from 1.6 to more than 3.5, while for a ratio between 0.8 and 1.1 the FCR varied from 1.85 to 2.15.

Results showed that feeding strategy and the amount of feed distributed had a big influence on the performance of the growth and the productivity of the fish farm. A limited quantity of feed, less than 60 % of the theoretical quantity recommended by the feed supplier’s, might induce an increase of the FCR and constrain the growth of the fish.

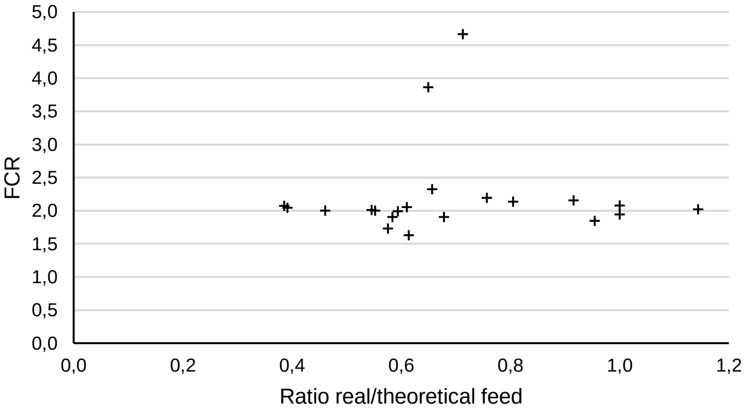


Figure 4.6: FCR as function of the ratio between the real feed consumed and the theoretical quantity needed

4.4 Conclusions

Previous exponential models (Mayer and al., 2008) could be good tools for estimating the growth of gilthead sea bream, but they must be adapted to the case of each particular marine farm, to obtain an acceptable prediction of growth. Batch 2-2010 was considered as the best batch fed at an optimal feeing ratio, and real fish grew at a very similar rate all the way to the harvesting size, which was reached in about 126 days. The models and specifically model 1, can be a good tool to simulate the growth under real rearing condition, if we assume that the fish were correctly fed. As it was demonstrated, the feed supply seems to be underestimated compared to the theoretical feeding rate provided by the feed producer and to the quantity of feed calculated for model 1 and 2. Having a lack on food supply might be a big constraint to reach the optimal growth for sea bream in marine cages and to run a predictable model that can lead with real growth.

Production of gilthead sea bream (*Sparus aurata L*) and sea bass (*Dicentrarchus labrax L*) has increased and consequently the sale price has declined, making it necessary to adjust production costs (feed, fingerling, labour, etc.) and increase income. An alternative to improve income could be the optimization of the production process and stock management, for example by optimizing feed ingredients, food rations, optimum stocking or harvesting size. (Jackson et al. 2015; Arechavala-Lopezetal et al 2017) claimed fish escapes as a major handicap for Mediterranean fish farmers, causing annual losses escape of fish from sea-cage aquaculture. Fish escape can be a single or a group of fish that make their way out of the net-pen. Principally, reared individuals escape from sea-cage fish farms due to technical and operational failures. It is, however, difficult to determine the proportion of escapes derived from storms, holes in netting (caused by predators or farmed individuals within the cage), and fish spills due to poor handling.

The goal was to highlight potential negative effects of escaped fish through a risk assessment. The escape of fish influences the feeding strategy, as it’s the case of the studied fish farm, located in the south part of the Mediterranean Sea, in Tunisia. This technical constraint can present a big handicap on the management of the fish farm, as it affects the feeding strategy and consequently the profitability of the production.

To estimate and optimize several management aspects, it is essential to have good growth models adapted to each species and area of production.

The Thermal-unit Growth Coefficient (TGC) model was reported by Mayer et al. (2008, 2009, 2012) for gilthead sea bream. When determining the production conditions, the TGC model becomes an interesting management tool for describing growth in marine farms.

In most of the studies that explore weight dynamics using mathematical models, a simple description of the evolution of the mean weight at a given time interval is considered, which is acceptable as a reasonable exercise of simplification. However, in aquaculture, the starting point is an initial population of fish provided by the hatchery whose weight follows a statistical distribution, which can be estimated from representative initial samples. It is undisputable that in-depth knowledge of various sizes in a batch at the end of the cycle would facilitate management in the aquaculture

Thus, in the event of achieving a good description of the changes in weight distribution versus time, a complete statistical description of the weight would be available at any time, and not only a simple average value. Quantile regression (Estruch et al, 2017) helps to estimate the evolution of the growth data distribution and is very suitable for analyzing data. Thus, the growth model allows simulations of growth, providing the variability of the weight throughout the production cycle and values closer to reality of the total biomass, and its size distribution which is the most important.

CHAPTER 5

GENERAL CONCLUSION AND PERSPECTIVES

5.1 Results summary

This PhD thesis represents one of the first monitoring of fish farms production system of Gilthead sea bream (*Sparus auarta*), in marine cage, located in Tunisia.

This study was designed to answer three critical questions about aquaculture management and requirements for profitable production system of marine fish farm.

- What are the fundamentals factors influencing the growth of Gilthead sea bream in marine cages?
- What is the importance to demonstrate the interaction between the different functional rates, for instance specific growth rate, specific feeding rate and feed conversion rate and the effect of water temperature fluctuations?
- What are the possibilities of thermal growth model to predict the growth under a real fish farming condition?

The aim of this last chapter is to discuss the main finding of this thesis and clear out the theoretical implication, limitations and perspective of this study.

To provide a precise and clear idea about the growth behaviour of sea bream, twenty-one cages were studied to assess the growth performance through six years of production. Firstly, assessment of growth was evaluated through time, and through seasonal temperature fluctuation. Secondly, the monitoring of the different functional rates, was conducted to determine their interactions and their dependency on seasonal temperature fluctuation.

An assessment of the time required for the fish to reach the final commercial size, using a model temperature and time dependent models, demonstrates a slow growth during time, compared to the predictable growth. Taking in consideration that the growth depends, also on food availability, the reason of such reduced growth was related to the feed management. The quantity distributed was in general underestimated and not obeying to the theoretical quantity of feed recommended based on the feeding rate of the supplier’s.

Having a lack on food supply might be a big constraint to reach the optimal growth for sea bream in marine cages and to run a predictable model that can lead with real growth.

5.2 Theoretical implication and limitations

This study proposes a practical method for the prediction of growth of gilthead sea bream in aquaculture. Many experimental studies were conducted with sea bream in recent years, each providing partial information regarding the general growth function, but different datasets often produced considerably different growth models. Frequently, the datasets do not cover adequately the argument (predictors) domain, for instance when the data only cover growth and fish weight (e.g., von Bertalanffy). Sometimes the data are unable to support the theoretical sophistication of the models. A reliable growth model is an essential tool in aquaculture management, and the approach taken here is to formulate the simple model which retains the essentials of the growth process. Thermal growth model was a good tool for predicting the growth of sea bream under real condition, if we assume that fish are correctly fed, and the feeding rate applied follow the recommended feeding rate of the supplier's.

5.3 Perspectives

The development of a suitable growth prediction model, adjusted to the real conditions of intensive production, could be an important tool for reducing the production costs by optimizing the daily food ration, the organization of management operations and the production plan. In the case of gilthead sea bream, the use of the 1/3 TGC model is useful in estimating the weight in the initial period of growth. At advanced stage of growth (>117g), it's advisable to use the 2/3 TGC model to estimate the growth. The Mixed TGC most is the most appropriate for long-term and final weight estimations along the complete cycle of growth (Mayer et al, 2012).

In aquaculture, the starting point is an initial population of fish provided by the hatchery whose weight follows a statistical distribution, which can be estimated from representative initial samples. It is undisputable that in-depth knowledge of various sizes in a batch at the end of the cycle would facilitate management in the aquaculture.

Applying the quantile regression TGC-mixed model presented by Estruch et al (2017) as a global representation of the variability of fish growth in the fish farm over the entire production cycle. The growth model allows simulations of growth, providing the variability of the weight throughout the production cycle and values closer to reality of the total biomass, and its size distribution which is the most important.

The information obtained from the growth simulation provided by the model is very powerful because it allows us to design and simulate sales plans taking the sale price into consideration, with a view to optimizing management and economic profits on each fish farm.

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