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An econometric viability model for ongrowing sole (*Solea senegalensis*) in tanks using pumped well sea water

J. García García[1]* and B. García García[2]

[1] IMIDA. Consejería de Agricultura y Agua. C/ Mayor, s/n. 30150 La Alberca (Murcia). Spain
[2] IMIDA-Acuicultura. Consejería de Agricultura y Agua. Apdo. 65. 30740 San Pedro del Pinatar (Murcia). Spain

Abstract

Sole (*Solea senegalensis*) is of great interest to marine aquaculture in the Mediterranean because of its relatively fast growth and good commercial prospects (high price). However, the wide mean annual variation in the temperature of Mediterranean sea water (14-26ºC) is a limiting factor for the ongrowing of this species; the optimum for this process is 19-20ºC. One of the possible mid-term solutions for ensuring a constant year-round temperature is to ongrow these fish in tanks containing pumped well water. The present work describes a mathematical model for estimating the values of economic variables associated with sole production (which to date have not been defined at the commercial level) for an onshore ongrowing plant using pumped well water at 19-20ºC. The economic variables studied include optimum load, the sale price of the final product, the cost of juveniles and feed (these last two are influenced by mortality which is still highly variable in this species), and finally the cost of electricity and oxygen (of great importance in onshore plants). The model allows different possible situations to be analysed on the basis of still undefined variables for ongrowing (juvenile cost, feeding, survival, etc.), and establishes under which conditions sole ongrowing would be profitable.

Additional key words: break even point, economics, profitability.

Resumen

Modelo econométrico de viabilidad para el engorde de lenguado en tanques de tierra con bombeo de agua de pozo

El lenguado (*Solea senegalensis*) es una especie que tiene un gran interés para la acuicultura marina dado su relativo rápido crecimiento y sus grandes posibilidades de comercialización con un alto precio de venta. En el mar Mediterráneo, sin embargo, la gran variación de la temperatura del agua (14-26ºC) parece ser el principal factor limitante para el desarrollo de empresas de engorde de lenguado, ya que la temperatura óptima de esta especie se sitúa en torno a los 19-20ºC. No obstante, uno de los posibles sistemas de engorde que podría llevarse a cabo a medio plazo es el engorde en tanques con bombeo de agua de pozo, que podría garantizar una temperatura constante a lo largo de todo el año. En el presente trabajo se desarrolla un modelo matemático de viabilidad/rentabilidad para una explotación de engorde de lenguado en tanques en tierra bombeando agua de pozo (temperatura de 19-20ºC), con la finalidad de estimar parámetros económicos ligados a la producción, que aún no están definidos a nivel del cultivo comercial del lenguado, tales como la carga óptima de engorde, el precio de venta del producto final, el coste del juvenil y de la dieta, estos dos últimos influidos por la mortalidad que aún puede ser muy variable en esta especie, y, finalmente, el coste de energía y suministro de oxígeno, que es importante en las instalaciones intensivas en tierra. El modelo permite analizar distintas situaciones posibles en función de las variables de cultivo no establecidas actualmente (coste de juveniles, alimentación, supervivencia, etc.) y establecer qué condiciones serían necesarias para que las explotaciones fueran rentables.

Palabras clave adicionales: economía, rentabilidad, umbral de rentabilidad.

Introduction

Sole aquaculture has attracted great interest in recent years, both at the research and commercial level. This is particularly true in Spain and Portugal since the species' rapid growth and high price provide a tremendous commercial opportunity. Although its reproduction in captivity has presented difficulties, large numbers of good quality larvae can now be obtained by following protocols developed by the *Instituto de Investigación y Formación Agraria y*

* Corresponding author: jose.garcia21@carm.es
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Pesquera (IFAPA) «El Toruño» (El Puerto de Santa María, Cádiz, Spain) (Anguis and Cañabate, 2005). A protocol is also available that ensures a high larval survival rate (Cañabate and Fernández-Díaz, 1999; Imsland *et al*., 2003). However, this survival rate depends on the quality of the feed provided (Estévez, personal communication). Many pathological problems can arise during ongrowing (Padrós *et al*., 2003; Toranzo *et al*., 2003), most of which seem to be related to high water temperatures (above 22-24ºC); the optimum temperature for this species is around 19-20ºC (García García *et al*., 2004a). In the Mediterranean, the wide mean annual range in sea temperature (14-26ºC) and in air temperature (which can directly affect the temperature of aquaculture tanks) seem to be the main factors limiting the success of ongrowing plants. A possible short and medium-term solution could be to ongrow sole in tanks using pumped well sea water to ensure a constant temperature throughout the year.

The aim of this work was to develop a mathematical viability/profitability model for estimating the minimum values of the production-linked economic variables associated with successful sole ongrowing (García García, 2001) (which remain undefined for commercial operations) in onshore plants using pumped well sea water at 19-20ºC. These variables include, for example, the maximum ongrowing load, the final sale price, the cost of juveniles and feed (both influenced by mortality rates, which may vary considerably in sole), and the costs of supplying energy and oxygen (which are considerable in land-based facilities) (García García *et al*., 2004b).

Material and Methods

Four theoretical land-based, intensive ongrowing facilities were designed, each with a different stocking density (10, 20, 30 and 40 kg m^{-2}) and annual output; these were then evaluated economically.

Three batches of juveniles were introduced into each of the four plant models to ensure the availability of commercial-sized samples throughout most of the year. These juveniles were assumed to have a mean body weight of 5 g and that they would be kept in 5 m diameter pre-ongrowing tanks before being passed to 12 m diameter polyester ongrowing tanks. Based on the experimental growth results of Rodríguez and Souto (2003) and an operating temperature of 19ºC, the duration of each production cycle was estimated at 12 months. The number of ongrowing tanks assigned

Table 1. Final load, production and number of pre-ongrowing tanks in each plant

Plant	Stocking density (kg m^{-2})	Production (Mg)	Pre-ongrowing tanks (5 m diameter)	Area occupied (ha)
A	10	100	22	3.5
B	20	200	42	3.7
C	30	300	64	3.9
D	40	400	46	3.9

—88— was the same in each plant, whereas the number of pre-ongrowing tanks varied from 22 to 86 (Table 1) since the number of juveniles also varied with the final cultivation load. The ongrowing tanks were assumed to be kept outdoors and fitted with a lid consisting of a galvanised iron frame covered with double plastic mesh. The pre-ongrowing tanks were assumed to be housed in an industrial warehouse. In all cases they were to be filled with pumped well sea water at a constant temperature of 20ºC (coinciding with the optimum temperature for sole growth). Liquid oxygen was used to reduce the costs of pumping. The flow rates and oxygen needs were calculated according to the oxygen consumption equations for the species (García García *et al*., 2004a). Calculations were then performed to determine the dimensions of the inlet and outlet pipes.

Data from a variety of sources were used for the construction of the model and for calculations, including information available in the public domain, in research papers, from administrative bodies, and from aquaculture companies. The technical characteristics and costs of production were obtained from different suppliers (Corelsa, Acuitec S.L., Disaplast S.A., among others) and from official price data bases (Official College of Architects of Madrid for construction materials, the Polytechnic University of Valencia for agro-food prices, etc.).

All the plants were designed with the same multipurpose building, a pumping shed, a tank warehouse, machinery and equipment, etc. Table 2 shows the initial theoretical investment made (K), including equipment, machinery and sundry costs (e.g., buildings, building licences and construction work, etc.). This varied between 2 and 3 million € (Table 2). A significant and direct relationship was assumed to exist (and was in fact confirmed) between the stocking density (SD) or plant type and the investment required (Fig. 1):

$$K = 40{,}197 \cdot SD + 2 \cdot 10^6$$

Table 2. Summary of investment costs for the four plants (€)

Item	Plant A	Plant B	Plant C	Plant D
Earth moving	65,100	68,820	72,540	72,540
Multi-purpose building/pumping shed	179,695	239,410	299,125	348,388
Water inlet pipes	18,770	20,825	22,939	23,588
Outlets and channelling	21,400	23,423	25,478	26,481
Pumping equipment and wells	189,000	298,400	383,800	469,200
Warehouse: pre-ongrowing tanks	183,650	342,775	508,300	668,950
Tanks	1,125,376	1,125,376	1,125,376	1,125,376
Decantation tanks/emissary	87,218	112,548	130,598	144,098
Urbanization (roads, paths, fences etc.)	60,490	64,430	68,687	69,868
O_2, injection and distribution	12,000	16,000	19,000	22,000
Machinery and equipment	75,000	112,500	140,625	161,720
Various	132,755	168,832	199,166	224,040
Total	2,150,454	2,593,338	2,995,633	3,356,248

Production costs

Sole production is intensive and requires the use of a commercial feed. According to Rodríguez and Souto (2003) and Chereguini *et al.* (2004), a conversion rate of 1 ($CR1 = 1$) might be expected. However, the sole is a bottom feeder and shows little activity when feed is supplied, and at least 20% may be lost in industrial ongrowing plants. The conversion rate therefore becomes 1.2 ($CR2 = 1.2$). In addition, the conversion index is affected by mortality. Since no data are available concerning mean survival rates for sole in industrial conditions, calculations were made for rates of between 60 and 100%, and conversion indices ($CR3$) were calculated using the equation:

$$CR3 = (LJ + DJ) / BP$$

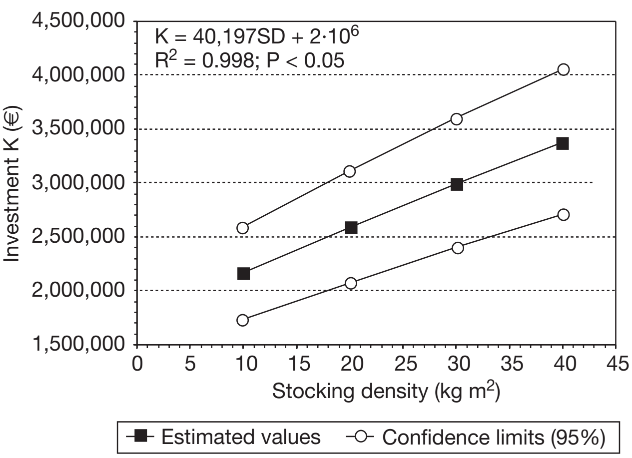

Figure 1. Direct relationship between stocking density (*SD*) and investment.

where *LJ* is the feed consumed by the surviving fish (*CR2*), *DJ* is the feed consumed by the lost fish (assuming a mean weight of 200 g), and *BP* is the biomass produced. The price of commercial feed was 1.5 € per kilo [including value added tax (VAT)]. Table 3 shows the effect of survival on the conversion rate and feed cost per kg of sole produced (C_F).

To determine the costs involved in pumping the water and the liquid oxygen supply (C_O), oxygen consumption (*OC*) models designed for sole were used (García García *et al.*, 2004a). To calculate the mean oxygen needs, a mean weight of 200 g per specimen was assumed at any given time of the year:

— Mean daily OC (expressed per hour since oxygen consumption varies over the day depending on the mean daily amount of feed consumed): 134.60 mg O_2 kg^{-1} h^{-1} – used to calculate the cost of electricity and injecting oxygen.

— Routine OC: 90.28 mg O_2 kg^{-1} h^{-1} – used to optimise costs.

— Maximum OC due to feeding: 159.09 mg O_2 kg^{-1} h^{-1} – used to calculate the pumping power needed.

To calculate the flow of water (Table 4) and the amount of liquid oxygen to add (Table 5), the following values were established:

Table 3. Conversion rate (*CR3*) and feed costs per kg of sole produced (C_F) as a function of survival

	Survival (%)				
	100	90	80	70	60
CR3	1.20	1.27	1.35	1.46	1.60
C_F (€ kg^{-1})	1.80	1.90	2.03	2.19	2.40

Table 4. Well water flow (middle, minimum, maximum flow, $m^3 h^{-1}$) in the different plants

Plant	Fmid	Fmin	Fmax
A	1,025	688	1,212
B	2,051	1,375	2,424
C	3,076	2,063	3,636
D	4,101	2,751	4,848

— (O_2) well water: 60% saturation (4.38 g m^{-3}).
— (O_2) water entering tank: 180% (13.13 g m^{-3}).
— (O_2) water leaving tank: 90% (6.56 g m^{-3}).

The cost of juveniles per kg of sole produced (C_J) also varies with survival. Table 6 shows how survival affects this cost. The cost of juveniles was set at 1.00 € unit^{-1} (including VAT).

Sensitivity analysis

The net present value (*NPV*) and initial rate of return (*IRR*) were calculated; these economic indices characterise any investment made in stock raising (Romero, 1985; Alonso and Iruretagoyena, 1992; Muñoz and Rouco, 1997), aquaculture (García García, 2001), and indeed many other activities (Peumans, 1977; Mao, 1986).

The *NPV* indicates the net gain generated by the project, and is calculated by subtracting the monetary units invested from the suitably homogenised total of monetary units the investment provides the investor. If the investment is not fractionated, the algebraic expression for a given homogenisation factor (interest rate) will be:

$$NPV = R_1/(1+i) + R_2/(1+i)^2 + \ldots + R_n/(1+i)^n - K$$

or:

$$NPV = \sum_{j=1}^{n} R_j/(1+i)^j - K$$

Table 5. Oxygen needs and injection costs in the different plants

Plant	O_2 injection ($m^3 h^{-1}$)	O_2 injection (m^3 year^{-1})	Annual cost[1] (€)	Cost per kg produced (€ kg^{-1})
A	6.68	58,560	12,385	0.248
B	13.37	117,119	20,594	0.206
C	20.05	175,679	28,803	0.192
D	26.74	234,239	37,012	0.185

[1] The figure takes into account the cost of the oxygen, the rental of storage tanks, and the rate of discharge.

Table 6. Initial number of juveniles needed to produce 1 kg of product (units kg^{-1}), and the cost of the same (C_J) as a function of survival. Mean commercial weight: 400 g

	Survival (%)				
	100	90	80	70	60
Units kg^{-1}	2.50	2.78	3.13	3.57	4.17
C_J (€ kg^{-1})	2.50	2.78	3.13	3.57	4.17

where *Rj* is the cash flow originated by the investment in year *j*, *n* the total number of years of the project, and *i* the interest rate.

Thus, when a project has a *NPV* greater than zero, it can be said that it is financially viable at the given interest rate. If, on the other hand, the *NPV* is negative, the project is not viable and should not be undertaken; its execution will provide the investor with a lower number of monetary units than those invested in it. The *NPV* is therefore a measure of the absolute profitability of an investment.

The *IRR* considers the investment made as if it were a loan of *K* monetary units (initial investment) which a given economic agent (the investor) lends to an abstract entity (the project), and is useful for determining the interest rate that the lender can obtain on his loan. The *IRR* acts as a type of indicator of the efficacy that an investment represents for the potential investor (Romero, 1985). This interest rate, λ, should satisfy the following if the investment is not fractionated:

$$K = \sum_{j=1}^{n} R_j / (1+\lambda)^j$$

To perform the sensitivity analysis, the variables used were investment (*K*), the cost of pumping the water and the liquid oxygen per kg sole produced (C_O), the cost of feed per kg of sole produced (C_F), the cost of juveniles per kg of sole produced (C_J), and the sale price in € kg^{-1} (*SP*). Table 7 shows the pre-established ranges for these variables; 243 possible alternatives (3^5) were generated for each plant. The margins of the variables have been adjusted to be as representative as possible; the most important variables were provided with a wide range (± 20%) because of their possible effect on the outcome. Multiple regression analysis led to the following equation:

$$Y = a + bK + cC_O + dC_F + eC_J + fSP,$$

where *Y* is the *NPV* or *IRR*, and *a*, *b*, *c*, *d*, *e* and *f* are constants derived from the model (García García, 2001; García García *et al*., 2004b).

Table 7. Range of variables used in the sensitivity and econometric analyses

Plant	K[1]	C_o[2]	C_F[3]	C_J[4]	SP[5]
A	1,720,363-2,580,545	0.68-1.01	1.80-2.40	2.50-4.17	10-13
B	2,074,671-3,112,006	0.66-0.99	1.80-2.40	2.50-4.17	10-13
C	2,396,506-3,594,759	0.65-0.98	1.80-2.40	2.50-4.17	10-13
D	2,684,998-4,027,498	0.65-0.48	1.80-2.40	2.50-4.17	10-13

[1] Investment. [2] Energy and oxygen costs per kg produced. [3] Cost of feed per kg produced. [4] Cost of juveniles per kg produced. [5] Sale price.

Results

Tables 8-11 show the out-payment and in-payment flow for year 2 in the econometric model and thereafter, based on the initial hypothesis laid out in Table 7. A mean price of 11.5 € kg^{-1} was set for in-payments.

Table 12 shows the cost analysis using the mean values of the variables considered. The production costs relative to the starting costs (mean values of the ranges established for the variables) varied from 9.89 € in Plant A to 8.24 € kg^{-1} in Plant D; thus, for a sale price of 11.5 €, the B/K index increases from 7.50% to 38.84%.

Table 8. Ordinary and extraordinary in- and out-payment flow (€) for Plant A (stocking density 10 kg m^{-2})

	Year 1	Year 2	Year 3 and suc.[1]
Ordinary out-payments			
1. Juveniles	334,000	334,000	334,000
2. Feed	210,000	210,000	210,000
3. Electricity for pumps	72,030	72,030	72,030
4. Liquid oxygen	12,400	12,400	12,400
5. Personnel	263,000	263,000	263,000
6. Fuel (Transfer pump, classifier...)	3,000	3,000	3,000
7. Water, energy, telephone for offices	2,460	2,460	2,460
8. Production insurance	57,000	57,000	57,000
9. Maintenance costs	9,703	19,406	19,406
10. Treatments	3,000	3,000	3,000
11. Others	3,450	3,450	3,450
12. Leasing	3,150	3,150	3,150
15. Publicity	5,750	5,750	5,750
Total	978,943	988,646	988,646
Extraordinary out-payments			
1. Oxygen injection equipment (year 10)			12,000
2. Pumping equipment and machinery (year 10)			163,000
Ordinary in-payments			
1. Sale of fish	1,150,000	1,150,000	1,150,000
Extraordinary in-payments			
1. Subsidy (30% of investment)		645,136	
2. Sale of equipment (years 10 and 20)			17,500

[1] Out-payments and in-payments in year 3 and successive years.

Table 9. Ordinary and extraordinary in- and out-payment flow (€) for Plant B (stocking density 20 kg m^{-2})

	Year 1	Year 2	Year 3 and suc.[1]
Ordinary out-payments			
1. Juveniles	668,000	668,000	668,000
2. Feed	420,000	420,000	420,000
3. Electricity for pumps	144,060	144,060	144.060
4. Liquid oxygen	20,600	20,600	20,600
5. Personnel	331,000	331,000	331,000
6. Fuel (Transfer pump, classifier...)	6,000	6,000	6,000
7. Water, energy, telephone for offices	3,696	3,696	3,696
8. Production insurance	114,000	114,000	114,000
9. Maintenance costs	11,698	23,397	23,397
10. Treatments	6,000	6,000	6,000
11. Others	6,900	6,900	6,900
12. Leasing	3,330	3,330	3,330
15. Publicity	11,500	11,500	11,500
Total	1,746,784	1,758,483	1,758,483
Extraordinary out payments			
1. Oxygen injection equipment (year 10)			16,000
2. Pumping equipment and machinery (year 10)			270,900
Ordinary in payments			
1. Sale of fish	2,300,000	2,300,000	2,300,000
Extraordinary in payments			
1. Subsidy (30% of investment)		778,001	
2. Sale of equipment (years 10 and 20)			28,690

[1] Out-payments and in-payments in year 3 and successive years.

Table 13 shows the absolute and relative costs for each item with respect to the total cost for each plant.

The equations obtained from the results of the multiple regression in the econometric analysis are as follows:

— Plant A (Production 100 Mg $year^{-1}$; stocking density 10 kg m^{-2}):

$$NPV = -5{,}967{,}716 - 0.71K - 1{,}672{,}882C_O - 1{,}635{,}143C_F - 1{,}635{,}143C_J + 1{,}635{,}143SP$$

(Coefficients $P < 0.001$; ANOVA, $P < 0.001$; Error of the estimate = 3,993.2; $R^2_{adj} = 0.999$)

$$IRR = -0.122\text{-}410^{-8}K - 0.041C_O - 0.041C_F - 0.040C_J + 0.047SP$$

(Coefficients $P < 0.001$; ANOVA, $P < 0.001$; Error of the estimate = 0.204; $R^2_{adj} = 0.913$)

— Plant B (Production 200 Mg $year^{-1}$; stocking density 20 kg m^{-2}):

$$NPV = -8{,}444{,}977 - 0.71K - 3{,}311{,}735C_O - 3{,}242{,}948C_F - 3{,}260{,}484C_J + 3{,}264{,}819SP$$

(Coefficients $P < 0.001$; ANOVA, $P < 0.001$; Error of the estimate = 49,581.0; $R^2_{adj} = 0.999$)

$$IRR = -0.008 - 710^{-8}K - 0.066C_O - 0.065C_F - 0.070C_J + 0.069SP$$

(Coefficients $P < 0.001$; ANOVA, $P < 0.001$; Error of the estimate = 0.017; $R^2_{adj} = 0.972$)

— Plant C (Production 300 Mg $year^{-1}$; stocking density 30 kg m^{-2}):

$$NPV = -10{,}935{,}077 - 0.71K - 4{,}847{,}202C_O - 4{,}905{,}430C_F - 4{,}905{,}430C_J + 4{,}905{,}430SP$$

Table 10. Ordinary and extraordinary in- and out-payment flow (€) for Plant C (stocking density 30 kg m^{-2})

	Year 1	Year 2	Year 3 and suc.[1]
Ordinary out-payments			
1. Juveniles	1,002,000	1,002,000	1,002,000
2. Feed	630,000	630,000	630,000
3. Electricity for pumps	215,837	215,837	215,837
4. Liquid oxygen	28,800	28,800	28,800
5. Personnel	399,000	399,000	399,000
6. Fuel (Transfer pump, classifier...)	9,000	9,000	9,000
7. Water, energy, telephone for offices	4,920	4,920	4,920
8. Production insurance	171,000	171,000	171,000
9. Maintenance costs	13,525	27,049	27,049
10. Treatments	9,000	9,000	9,000
11. Others	10,350	10,350	10,350
12. Leasing	3,510	3,510	3,510
15. Publicity	17,250	17,250	17,250
Total	2,514,192	2,527,716	2,527,716
Extraordinary out payments			
1. Oxygen injection equipment (year 10)			19,000
2. Pumping equipment and machinery (year 10)			369,425
Ordinary in payments			
1. Sale of fish	3,450,000	3,450,000	3,450,000
Extraordinary in payments			
1. Subsidy (30% of investment)		898,690	
2. Sale of equipment (years 10 and 20)			38,843

[1] Out-payments and in-payments in year 3 and successive years.

(Coefficients P < 0.001; ANOVA, P < 0.001; Error of the estimate =11,570; R^2_{adj} = 0.999)

$$IRR = 0.101 - 7 10^{-8} K - 0.079 C_E - 0.080 C_P - 0.079 C_A + 0.077 SP$$

(Coefficients P < 0.001; ANOVA, P < 0.001; Error of the estimate = 0.018; R^2_{adj} = 0.972)

— Plant D (Production 400 Mg year^{-1}; stocking density 40 kg m^{-2}):

$$NPV = -13{,}243{,}778 - 0.76K - 6{,}648{,}304 C_E - 6{,}540{,}573 C_P - 6{,}540{,}735 C_A - 6{,}540{,}518 SP$$

(Coefficients P < 0.001; ANOVA, P < 0.001; Error of the estimate = 354,500; R^2_{adj} = 0.999)

$$IRR = 0.156 - 7 10^{-8} K - 0.085 C_E - 0.086 C_P - 0.084 C_A + 0.082 SP$$

(Coefficients P < 0.001; ANOVA, P < 0.001; Error of the estimate = 0.020; R^2_{adj} = 0.976)

All the coefficients for both equations per plant are significantly different to zero (P < 0.01). From an economic point of view, the equations are valid as long as the signs of their components are correct.

Discussion

The area required by the plants varied between 3.5 and 3.9 ha, depending on the stocking density. As with turbot, the ongrowing of sole in land-based tanks involves a large area because of the bottom dwelling behaviour of the species (a problem for the Mediterranean coast where this activity has to compete with others —particularly construction—for the limited

Table 11. Ordinary and extraordinary in- and out-payment flow (€) for Plant D (stocking density 40 kg m^{-2})

	Year 1	Year 2	Year 3 and suc.[1]
Ordinary out-payments			
1. Juveniles	1,336,000	1,336,000	1,336,000
2. Feed	840,000	840,000	840,000
3. Electricity for pumps	287,867	287,867	287,867
4. Liquid oxygen	37,200	37,200	37,200
5. Personnel	467,000	467,000	467,000
6. Fuel (Transfer pump, classifier...)	12,000	12,000	12,000
7. Water, energy, telephone for offices	5,664	5,664	5,664
8. Production insurance	228,000	228,000	228,000
9. Maintenance costs	15,188	30,377	30,377
10. Treatments	12,000	12,000	12,000
11. Others	13,800	13,800	13,800
12. Leasing	3,510	3,510	3,510
15. Publicity	23,000	23,000	23,000
Total	3,281,229	3,296,418	3,296,418
Extraordinary out payments			
1. Oxygen injection equipment (year 10)			22,000
2. Pumping equipment and machinery (year 10)			460,920
Ordinary in payments			
1. Sale of fish	4,600,000	4,600,000	4,600,000
Extraordinary in payments			
1. Subsidy (30% of investment)		839,062	
2. Sale of equipment (years 10 and 20)			48,292

[1] Out-payments and in-payments in year 3 and successive years.

land available). Plants would also have to be close to a source of sea well water of sufficiently high quality, which also reduces the number of possible sites.

Table 13 shows that the relative cost of depreciation (fixed) and the relative cost of personnel diminish with increasing production capacity, i.e., a scale economy applies, as with species as different as sea bream (Gasca-Leyva *et al.*, 2001; García García *et al.*, 2006), tilapia (Vera-Calderón, 2003) or cat fish (Keenum and Waldrop, 1998). Consequently, the remaining costs take on greater relative importance, especially the cost of juveniles and personnel. In the case of the 400 Mg year^{-1} plant (D), these represented 61.95% of the total production cost.

Table 12. Analysis of costs calculated with set starting prices (mean values of range)

Plant	Production (Mg)	Investment (€)	Absolute costs (€)	Relative costs (€ kg^{-1})	Sales (€)	Profit (€)	*B/K* (%)
A	100	2,150,454	988,646	9.89	1,150,000	161,354	7.50
B	200	2,593,338	1,758,483	8.79	2,300,000	541,517	20.88
C	300	2,995,633	2,527,716	8.43	3,450,000	922,284	30.79
D	400	3,356,248	3,296,418	8.24	4,600,000	1,303,582	38.84

B/K: profit/investment ratio.

Table 13. Absolute (in €) and relative (in %) costs of the different plants

Item	Plant A (100 Mg)		Plant B (200 Mg)		Plant C (300 Mg)		Plant D (400 Mg)	
	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel
Depreciation	125,023	11.23	158,357	8.26	188,625	6.94	216,104	6.15
Juveniles	334,000	30.00	668,000	34.84	1,002,000	36.89	1,336,000	38.04
Feed	210,000	18.86	420,000	21.91	630,000	23.19	840,000	23.91
Electricity and O_2	84,430	7.58	164,660	8.59	244,637	9.01	325,067	9.25
Personnel	263,000	23.62	331,000	17.27	399,000	14.69	467,000	13.30
Production insurance	57,000	5.12	114,000	5.95	171,000	6.30	228,000	6.49
Others	40,216	3.61	60,823	3.17	81,079	2.98	100,351	2.86

The relative cost of electricity for pumping and liquid oxygen, about 9% of the total in all cases, was very similar to the 8.20% calculated by García García (2001) for the onshore production of 200 Mg of sea bream. In the same work, depreciation represented 6.09% of the investment, which contrasts with the 8.26% of Plant B (200 Mg year^{-1}) (Table 13). This difference can be explained by the large areas needed for ongrowing sole and the larger infrastructure necessary. Comparing the onshore cultivation of sole with the offshore cultivation of the most widely cultivated species in the Mediterranean (gilt head bream) for the same size plant (see Gasca-Leyva *et al.*, 2001; García García *et al.*, 2006), offshore plants would involve much lower depreciation: 6.15% for 400 Mg year^{-1} of sole and 3.15% and 4.20% for gilthead bream. Further, ongrowing gilthead bream in sea cages involves no electrical pumping costs.

According to the cost analysis (using the mean values of the different variables –Table 7), the break-even point for the business coincided with the absolute or relative production costs. In the case of Plant A, this cost was 9.85 € kg^{-1}, which is near the sale price of 11.50 € kg^{-1}. This implies a *B/K* index of 7.50%, which is not a very sound investment when considering the high risks involved and the alternative of risk-free flat rate bank accounts. Plant B, on the other hand, with its load of 20 kg m^{-2}, relative cost of 8.79 € kg^{-1} and *B/K* index of 20.88%, is more attractive to the would-be investor – although much would still depend on the sale price. In the short and medium terms, therefore, production costs would need to be strictly controlled to compensate for a drop in the sale price due to an increase in supply. Plants C and D are certainly interesting from an investment point of view.

In sensitivity and econometric analyses, each farmer can use the variables that refer to his/her particular objectives. In stock raising, the *NPV* and *IRR* may depend on more general variables, e.g., for dairy cattle the important variables are investment and cash flow (Rouco and Muñoz, 1997). However, in still-emerging production activities such as aquaculture, the number of variables is higher since certain production data (cost of feed and juveniles, sale price, etc.) are as yet not well determined. For this reason, this work, and that of Thacker and Griffin (1994) who studied red drum (*Sciaenops ocellatus*), set out to determine the values associated with variables such as growth, mortality, sale price and feed price.

Based on the equations obtained, a number of situations were simulated (Figs. 2-7), from which the main conclusions of the present work were drawn. The minimum value of the *IRR* estimated to be economically interesting for this activity was 13-16% (since aquaculture in general is considered a business of considerable risk). The ongrowing of sole in land-based plants using well water with a constant temperature throughout the year (19-20ºC) may be profitable in the Mediterranean

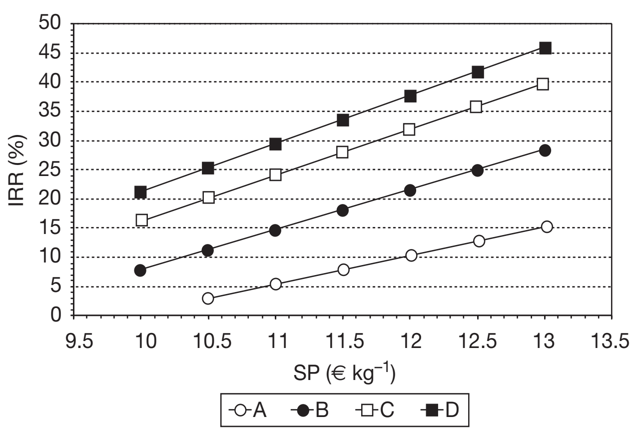

Figure 2. Variation in initial rate of return (*IRR*) according to plant type and sale price (SP).

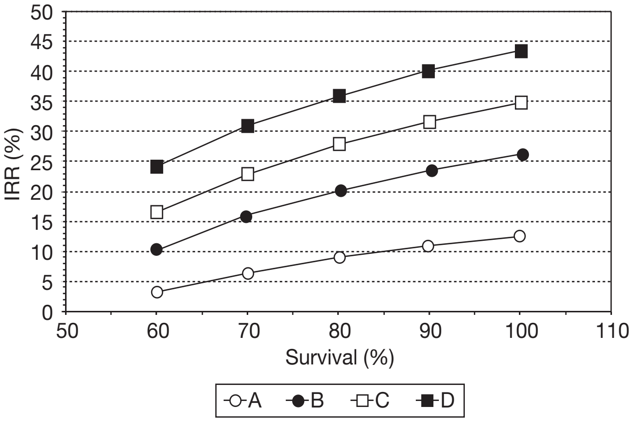

Figure 3. Variation in *IRR* according to plant type and survival.

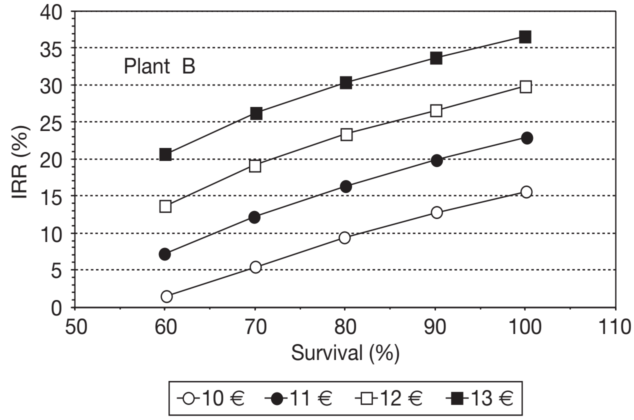

Figure 4. Influence of sale price (10-13 € kg^{-1}) and survival on *IRR* in Plant B (20 kg m^{-2}).

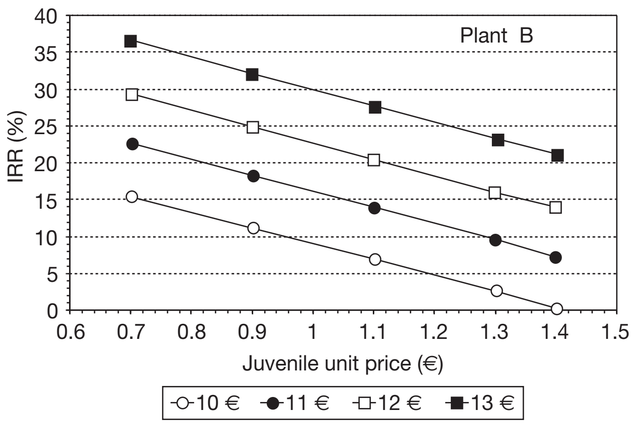

Figure 5. Influence of sale price (10-13 € kg^{-1}) and juvenile unit price on *IRR* in Plant B (20 kg m^{-2}).

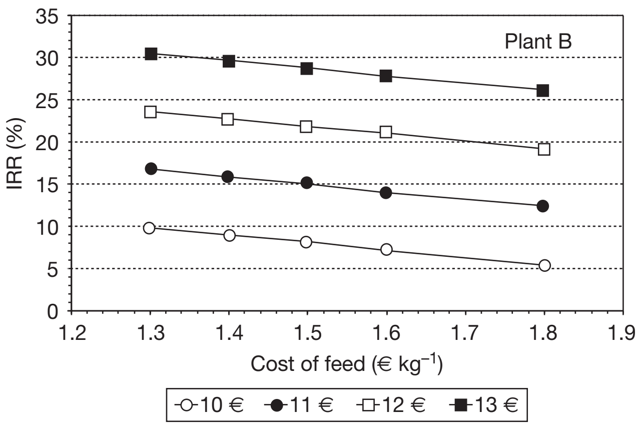

Figure 6. Influence of sale price (10-13 € kg^{-1}) and cost of feed on *IRR* in Plant B (20 kg m^{-2}).

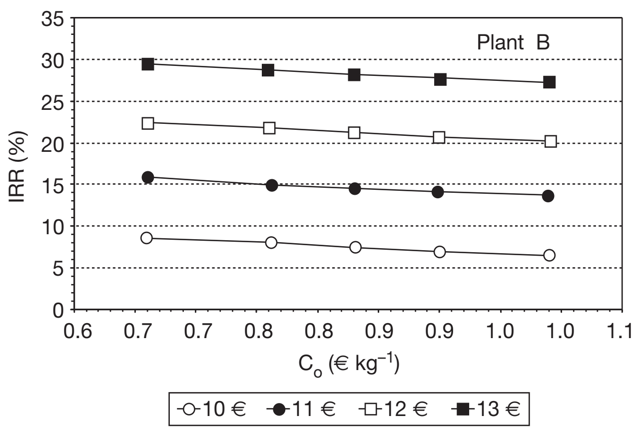

Figure 7. Influence of sale price (10-13 € kg^{-1}) and energy and oxygen costs on *IRR* in Plant B (20 kg m^{-2}).

area, although the activity is limited by the amount of space needed and the availability of marine wells with water of sufficient quality. However, the cultivation load must be above 20 kg m^{-2}, survival must exceed 80%, and the sale price must be at least 11 € per kilo. Production costs must be optimised in case the sale price drops.

Plant type A (stocking density 10 kg m^{-2}) was not economically viable even with a sale price of 13 € kg^{-1} and 100% survival (which is not very likely).

Plant type B (stocking density 20 kg m^{-2}) was viable, but this depended very much on the sale price; below 10.50-11 € kg^{-1} the investment would be questionable. Production costs would need to be strictly controlled, particularly the cost of juveniles and feed. Further, a survival of > 80% would be necessary and the sale price could not drop below 11 €. If the sale price reaches 12 €, a 70% survival rate would be acceptable. If, on the other hand, the price dropped to 10-11 €, the price of juveniles could not exceed 0.7-0.9 € per unit (incl. VAT) and feed 1.3-1.4 € kg^{-1} or the conversion rate would increase. In any event, the cost of feed and obtaining juveniles would need to be kept as close as possible to the lower limits of these ranges.

Plants of types C and D would be highly profitable, though their characteristics might be rather optimistic since no studies exist that confirm a load of 30-40 kg m^{-2} can be achieved without a significant reduction in growth, or whether a 70-80% survival rate can be sustained.

In conclusion, the results suggest that the ongrowing of sole in the Mediterranean area is not likely to reach the production levels associated with gilthead bream, and that farms could only be established in very specific areas. In the case of a developing and expanding sector such as marine aquaculture, econometric models can be very useful for determining under which conditions ongrowing can be profitable.

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