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OPTION VALUE AND OPTIMAL ROTATION POLICIES FOR AQUACULTURE EXPLOITATIONS.§

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Summary.

Evaluating an aquaculture exploitation is extremely difficult because of the high level of uncertainty regarding both the farmed resource and output prices. That is why option pricing methodology may be preferable to traditional discounted methods, that cannot properly capture the management flexibility of the exploitation.
This paper presents several models, based on Real Option theory, sufficient for determining not only the value of an aquaculture exploitation under management flexibility but also, the optimal rotation policy.
Moreover, the paper turns to calculate the risk of an aquaculture exploitation by using the Value at Risk (VaR) methodology.
To illustrate the nature of the solutions, a case based on the "mussel" sector in Galicia (Spain) is considered. Given the obtained value of the risk is higher than the option value itself, the mussel sector appears to be a risky sector.

Keywords: Real Options, Value at Risk (VaR), Aquaculture Exploitations.
JEL Code: G13, Q22

1. INTRODUCTION

Aquaculture is the farming or breeding of living aquatic beings, such as fish, crustaceans, molluscs, etc., for example, or what in economic terms we can define as the production of marine beings. Empirical evidence proves that today aquaculture is a very important commercial activity, especially in Asia, Latin America, the United States of America and Europe, due, in part, to an increase in the world demand for products deriving from the fishing industry.
This increase is a consequence not only of the continued growth of the world population but also, of the generalized over-exploitation that fisheries have been suffering over the last decades, an over-exploitation which makes it thinkable that many of the fishing resources caught today will exhaust their biological limit within just a few years.

Economic interest in the aquaculture sector is more than justified, bearing in mind that the competitive position of marine farming products throughout the world, and in particular in Spain, has grown in recent years, boosting to a large extent not only

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the entry of new competitors from third countries into the sector but also, the consolidation of those already existing (in particular, Spain is attracting more attention as a centre for fish farms on account of its strategic situation). The *Aquaculture white paper* considers that this sector has a potential growth rate of 20-25%, as an alternative option to traditional fishing, 70% of whose international fishing grounds are presently being over-fished. Labarta (2000) underlines that, with respect to the European Union, aquaculture produces almost a million and a half tons, which is more than 15% of fishing production. It should also be emphasized that the importance of aquaculture as a sector for the future lies not only in the capacity to produce or in present-day production but, because it takes on a new perspective which meets market behaviour and fish product consumption trends. González Laxe (2001) ensures us that, we are witnessing the transition from an emerging economic activity to an activity that is managerially consolidated. Having said that, the author admits that although many are the factors that favour the growth of the sector, we cannot remain blind to others which might limit it, such as, for example, the high level of uncertainty the sector is subject to, the Law on Coastlines itself, the family nature of said businesses, the generalized and global lack of aquaculture insurance policies, as well as the already-mentioned increased incorporation of third countries from the Mediterranean, especially, Greece, Turkey and Morocco.

The economic study of an aquaculture plant allows us to distinguish between its two basic characteristics (González (2001)): its dependence on the natural environment and its productive introduction into a very busy market. Such characteristics can be considered threats to the sector if action is not taken to properly deal with them; having said that, unlike the fishing sector (in which man cannot influence the recruitment and renovation of the resource), aquaculture activity helps increase the productivity of the natural environment and modify, although perhaps only partially, the product in terms of the levels of demand, among other factors. In this sense, aquaculture businesses are capable of adapting both to the biological as well as the changing economic context within which they carry out their activity, with the aim of optimising their economic management .

By biological context, we mean diverse factors such as illnesses,[1] , climatic conditions,[2] research into the biology of the species and the marine environment itself,[3] and other extrinsic aspects[4] which can alter the quantity of the resource farmed. Insofar as the economic context is concerned, we are referring mainly to factors such as the incipient entry of new competitors into the sector, as well as the very homogeneity of the resources farmed, which imply that this sector is habitually associated with highly volatile prices.

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[1] The Aquacultural white paper underlines the enormous importance that illnesses have on the resources farmed, not only on account of the high number of different kinds of illnesses but also because many of them imply a high mortality rate (up to 90%) within the species affected.

[2] An example of this, the storms in Galicia which have, on numerous occasions, caused species such as the mussel to be wrenched from the ropes hanging from the mussel beds.

[3] The Aquaculture white paper underlines that today, research into the biology of species is scant. In the same way, the marine environment remains a mystery, as it has been proven that each coastline or river behaves differently.

[4] Among the many extrinsic factors which can effect the resources farmed, we would underline the case of the red tides, which are having such a negative effect on mussel production in the Galician rias (Spain). The presence of toxins in the marine environment might delay collection until spawning begins, causing a deterioration in the quality of the products.

However from an economic point of view it is difficult to find an evaluation method, under the uncertainty factors, capable of incorporating the value of the adapting capacity mentioned above, that is, to find an evaluation method considering the management flexibility of the exploitation. The traditional evaluation methods (such as, for example, the Net Present Value (NPV)) are based on implicit assumptions referring to the future scenario of future cash-flow (that is, they anticipate the quantity produced and the prices), in spite of the fact that the way in which such cash-flow takes place might be different to what was expected initially, as a result of the uncertainty existing. These methods are valid in a deterministic context, but not in a case to the contrary, as they ignore management flexibility and that is why they could lead to short-sighted decisions being taken which could, in turn, lead to a loss in market position. In this study, the need to use the Real Options Theory instead of the traditional discount methods as an evaluation method in a context of great uncertainty is promoted. This theory not only allows us to conceptualise but also to quantify the management flexibility element. However, this does not mean that traditional methods should be abandoned altogether, rather seen as the basis for this Real Options methodology.

The evaluation of real options has been applied within a large variety of contexts, such as investments in natural resources, farming and agriculture, lease contracts, government regulations and subsidies, foreign investments and new projects, among others. (Trigeorgis (1996),). The first cases in which they could be applied are in the field of investment in natural resources. We could quote here Brennan and Schwartz (1985), McDonald and Siegel (1986), Paddock, Siegel and Smith (1988), Bjerksund and Ekern (1990), Slade (2001).
Later, it was applied to investment in renewable natural resources, in particular forestry resources, where we could quote: Morck, Schwartz and Stangeland (1989), Thomson (1992), Hughes (2000), Brazee and Bulte (2000). And recently, it has been extended to the field of fishery resources, Li (1998), Murillas (2001).

2 EVALUATING AN AQUACULTURE FARM AS AN EUROPEAN CALL OPTION.

Firstly, before giving a full description of the valuation model, it is quite convenient to identify the uncertainty sources. In this sense, the model assume there exists uncertainty with respect to the resource output price for different reasons:

- From a biological point of view, the toxins in the water usually cause a deterioration in the quality of the meat of the species farmed. To this respect, we would mention the case of the “Red Tides”, a phenomenon wchich habitually affects the aquaculture sector negatively.

- From an economical point of view, the growing introduction of competitors into the sector, which usually goes hand-in-hand with a drip in prices and therefore a loss of profit.

2.1 Notation

c: Value of the opportunity to exploit the aquaculture exploitation (or the value of the exploitation).

S: resource spot price (output price).

t=0: present moment at which it is obtained the future cash-flows valuation.

n: period basis on which there is the granting of the right to carry out the activity.

2.2 Assumptions.

i) The option to exploit the farm is valued by risk-averse investors;

ii) There are no arbitrage opportunities.

iii) There exists neither transaction costs nor taxes.

iv) There is no cost of closing and opening the aquaculture farm.

v) The convenience yield is unimportant. There is no expectative about the scarcity of the resource because the quantity of the resource produced each season is known beforehand and, so, there is no uncertainty surrounding it.

vi) The spot price follows a geometric Brownian motion:

$$\frac{dS}{S} = m dt + s dz, \qquad (2.1)$$

where:

m : local trend in the price, it may be stochastic.

s : instantaneous standard deviation of the spot price, assumed to be known.

dz : increment to a standard Gauss-Wiener process. This satisfies:

$$dz = e\sqrt{dt}, \quad siendo \quad e \; N(0,1).$$

vii) The specie farmed reaches maturity in months, m. There is no flexibility concerning the moment in which the product farmed is collected, which will take place at the end of each of the *n* periods (on the date *m*).

2.3. Option value. An European call option.

Every of the n periods of the aquaculture exploitations, the manager takes a similar contingent decision, that is, at the end of every period (assumption vii) he decides whether or not to collect the resource, given both the economic and biological aspects (Figure 1). If he does it, he obtains a cash-flow but if not, the cash-flow will be zero. This decision can be looked on as an “European call option”. Notice, the holder of an option on a farmable marine asset has the right, but not the obligation, to incur the resource exploitation (and so market cost) and receive the cash-flow derived from this activity. This right has a value named “European call option”.

Consequently, in such a way, at the present time the evaluation of the aquaculture plant would be looked as the sum of the n independent European options (see Figure 2).

$$Exploitation \quad Value_{t=0} = \sum_{j=1}^{n} c_j . \qquad (2.2)$$

where c_j is the European call option value.

Figure 1
Contingent decision at the end of every exploitation period.

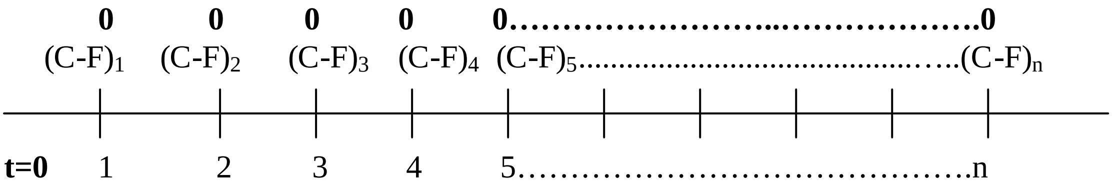
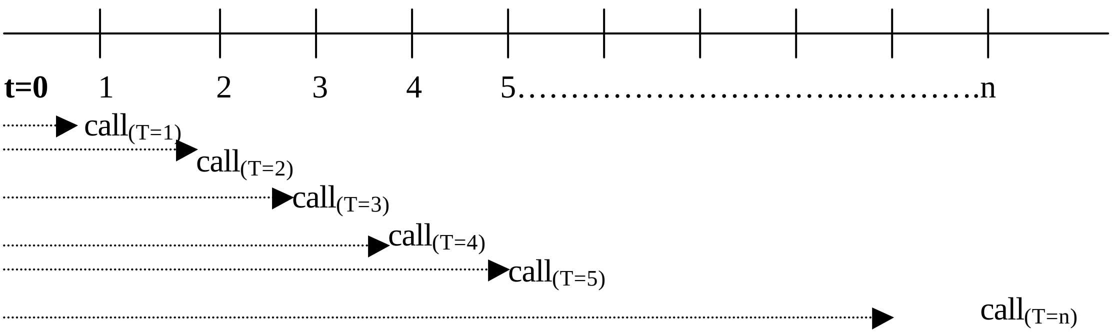


Figure 2
The European option value for an aquaculture exploitation.



In order to obtain[5] the value of said European options it is use the well-know model of Black and Scholes. Do not be worry because the fact this kind of real options are not exchanged in actual markets, because the only interesting question is how much would they cost if they could be sold in markets.

$$
\begin{aligned}
& call_t\,(j=T) = \left\{ S(t)N(d_{1j}) - Cte(T)e^{-rj}N(d_{2j}) \right\}; \\
& donde: \\
& d_{1j} = \frac{\ln(S/Cte) + (r + \frac{\sigma^2}{2})j}{\sigma\sqrt{j}}; \qquad\qquad (2.3) \\
& d_{2j} = \frac{\ln(S(Cte) + (r - \frac{\sigma^2}{2})j}{\sigma\sqrt{j}} = d_{1j} - \sigma\sqrt{j}.
\end{aligned}
$$

where:

Cte(T): strike price on the option maturity time.

N(.): accumulated probability distribution function of a normal variable with average zero and variance one.

Note that the difference among the said options resides in the maturity time (*T=1,2,3........n*), the current price of the resource, *S*, is common to all of them.

The expression (2.3) offers a neutral to the risk valuation given that it does not depend on the parameter, μ, but on the risk-free interest rate, *r* (Constantinides (1978).

The total exploitation value is given by the following expression:

$$Individual \quad Value_{t=0} = \left\{ S(t)\sum_{j=1}^{n} N(d_{1j}) - Cte(T)\sum_{j=1}^{n} e^{-rj} N(d_{1j} - \sigma\sqrt{j}) \right\} \qquad (2.4)$$

$$Global \quad Value_{t=0} = h_j \left\{ S(t)\sum_{j=1}^{n} N(d_{1j}) - Cte(T)\sum_{j=1}^{n} e^{-rj} N(d_{1j} - \sigma\sqrt{j}) \right\} \qquad (2.5)$$

where, h_j, is the quantity of the resource both produced and harvested.

3. EVALUATING AN AQUACULTURE FARM AS AN AMERICAN CALL OPTION. THE "*WAIT AND SEE*" OPTION.

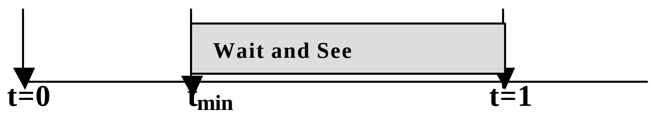
In this section, it is looked at a model of options which allows us to relax some of the assumptions considered above.

[5] See Black y Scholes (1973) y Merton (1973).

- It is now took into account uncertainty as to prices but also as to *quantities*. Many are the biological factors, such as the well-known “afloramiento” phenomenon, which if the effects of which were to become a reality ca be controlled, cannot be predicted affecting the quantity of resource farmed inevitably. The expectative about the scarcity of the resource are considered by introducing the *Convenience Yield* parameter.

- The model proposed now allows for flexibility to be increased in the following sense: it considers that the resource can be extracted at *any time* after a given minimum and maximum, *m* (see Figure 3). To alter the extraction time will allow the manager to anticipate to all times possible downward changes both in prices and quantities and, therefore, to increase the profitability obtained.

Figure 3
Temporary decision horizon.



The threshold t_{min} represents the minimum time period the specie farmed must remain in the plant until it is mature enough to be marketed. This threshold must be determined on the basis of certain biological criteria. Take, for example, the first period considered. In the shaded area, between t_{min} and t=1, the manager has the right to decide whether to collect the resource, and kill the option, or wait, and keep the option to take in the resource open, until the maturity time at the latest. This decision can be seen as an American[6] call option.

3.1 Notation.

Let:

C: Value of the opportunity to exploit the aquaculture exploitation.

k: Convenience Yield.

The Convenience Yield: interpretation.

The concept of convenience yield can be interpreted in different ways. In the area of natural resource evaluations,[7] writers usually interpret it, as the reflection of future expectations of a scarcity of resource, therefore, the greater this tax the greater the

[6] It is considered an American call option because it can be used at any time up until the maturity date, unlike European call options which can only be used at the maturity date.
[7] Some writers have associated convenience yields with losses of profitability. This concept is usually identified with the payment of a continuous dividend tax. See, McDonald y Siegel (1986), Paddock, Siegel y Smith (1988), Bjerksund y Ekern (1990).

expectations of a shortage, and, therefore, the greater the incentive to use the right to collect the resource earlier.

Note that only if said convenience yield takes on a null value would the manager of the American options not use the option before the maturity date, m.

The introduction of a convenience yield implies the revision of the assumption (vi) about the dynamics of the resource price. Risk-neutrality conditions implies that the drift term or rate, m must be replaced by the return on the safe asset, r minus the convenience yield, k.

3.2 Option Value.

Every of the n periods of the aquaculture exploitations, the manager takes a similar contingent decision, that is, he decides whether or not to collect the resource, at any time of the temporary decision horizon (see Figure 3). This decision is taken given both the economic and biological aspects. If he does it he obtains a cash-flow but if not, the cash-flow will be zero. Notice, the holder of an option on a farmable marine asset has the right, but not the obligation, to incur the resource exploitation (and so market cost) and receive the cash-flow derived from this activity. This right has a value named "American call option".

For every period it is obtained not only the present value of the cash-flows but also, the value of the option of wait and see. To wait in order to obtain new information about the uncertainty on both, the resource and the price, has a value and this one must be considered as part of the exploitation value.

The present value of the exploitation can be defined as the sum of a series of American options:

$$Unit \quad Value_{t=0} = \sum_{j=1}^{n} Call(T = j) \tag{3.1}$$

Every of the American options can be obtained as following:

$$Call(T = j) = \left\{ call(T = j) + A\left(\frac{S}{S^*}\right)^g \quad when\ S < S^* \right\}, \tag{3.2}$$

$$Call(T = j) = S - Cte. \tag{3.3}$$

where:

S* is the critical price, price at which it is optimal collect the resource. It must satisfy the following equation:

$$S^* - Cte(T) = c(S^*, t) + \left\{1 - e^{-kj} N(d_{1j}(S^*))\right\} \frac{S^*}{g}, \tag{3.4}$$

Note the value of the European call options, *c*(.) must be rewritten so as to introduce the convenience yield parameter:

$$call_t(T = j) = \left\{S(t) e^{-kj} N(d_{1j}) - Cte(T) e^{-rj} N(d_{2j})\right\}; \tag{3.5}$$

where:

$$d_{1j} = \frac{\ln(S/Cte) + (r - k + \frac{s^2}{2}) j}{s\sqrt{j}};$$

$$d_{2j} = \frac{\ln(S/Cte) + (r - k - \frac{s^2}{2}) j}{s\sqrt{j}} = d_{1j} - s\sqrt{j}.$$

$$g = \left[-(b - 1) + \sqrt{(b-1)^2 + \frac{4a}{h}} \right] / 2,$$

$$b = \frac{2(r-k)}{s^2},$$

$$a = \frac{2r}{s^2}$$

$$A = \left\{1 - e^{-kj} \left[N(d_1(S^*))\right]\right\} \left(\frac{S^*}{g} \right).$$

4. SOME EXPLOITATION STRATEGIES BY USING THE OPTION THEORY.

<table>
<tr><th>Economic and biological factors</th><th>Option value for the exploitation</th><th>Optimal strategies</th></tr>
<tr><td rowspan="2">Biological Phenomena

-High rates of resource mortality as a result of illness, toxins in the water, etc.

-Adverse climatologically conditions, “afloramiento” phenomena, etc.

Economic Context

-The fact the product is perishable.

-Possibility of a rapid increase in production and, the introduction of new competitors from third countries into the sector.

- High level of product homogenei</td><td>PRESENT VALUE OF THE EXPLOITATION[1]
=
PRESENT VALUE OF THE FUTURE CASH-FLOWS
+
OPTIMAL EXPLOITATION POLICY.</td><td>To exploit or not the farmed resource at a fixed future time (at which the resource will be collected)</td></tr>
<tr><td>PRESENT VALUE OF THE EXPLOITATION[2]
=
PRESENT VALUE OF THE FUTURE CASH-FLOWS
+
WAIT AND SEE OPTION VALUE
+
OPTIMAL EXPLOITATION POLICY</td><td>To exploit or not the farmer resource at any time along the temporary decision horizon.

OPTIMAL ROTATION POLICY (OPTIMAL RESOURCE SIZE)

To exploit or not the resource after having fisnished the temporary decision horizon.</td></tr>
</table>

[1] European option models.
[2] American option models.

5. APPLICATION TO THE CASE OF THE GALICIAN MUSSEL SECTOR.

The mussel sector represents one of the most representative examples insofar as aquaculture production in Galicia and in Spain concerned. Labarta and Corbacho (2002) study the present-day situation of Galician mussel production. These writers consider the profitability of the sector has been affected recently by several aspects which should be taken into account and, which it will be discussed below:

From an Economical point of view:

- Although mussel imports by Spain are not important, the figures are indicative of market segments which have been neglected by Spanish production (it should not forget that Spain is the leading European producer). To be precise, Labarta (2000) emphasizes that it would be necessary for the Galician sector to take up positions in other areas of the Spanish coastline to cover the demand for a smaller-sized mussel which, at the moment, is being marketed and the demand met by other countries. In this way, it is clear that Galicia production has still not developed wholly the market potential within its reach, because up until now the smaller-sized resource has not been extracted.

- Labarta (2000) also underlines the growing increase in the processed product market that affects the fresh mussel price. It must be considered not only to the differences between one market and the other but also, that the competitive advantages of proximity to markets of the fresh markets disappear in the processed product markets, where said proximity does not represent a competitive advantage and, therefore, the impact of products of other origins can have direct an immediate effects on Spanish production.

From a biological point of view:

- It would be mentioned the case of the “Red Tides”, a phenomenon which habitually affects the mussel sector in Galicia. This phenomena habitually causes the deterioration in the quality of the mussel which are having a negative effect on the mussel sector production. This phenomena has been observed since 1976, but although its consequences are very well known, it is not possible to predict them.

It seems logical to think that in an uncertain environment, as the one described above, adopting a flexible management approach is preferable to passive one. That is why this section offers an option valuation of the mussel sector in Galicia by using the models presented in the previous sections.

5.1 Economic and Biological data.

The numerical illustration is carried out for the total mussel sector in Galicia, for the years between 1995 and 2000. The option models are unaware of the series of future mussel prices, the only information they are based on is present price. The starting price, in January 1995 is taken to be 0,35 euros/ Kg, an average price for mussels that year. Insofar as the marketed production (which differs from the production of mussels in mussel beds) in thousands of tons is concerned, this had been obtained for the years 1995 to 2000, being the information for the last year still provisional. With respect to the operational costs, it is used of the part of the costs which refer to own consumption of the farmed product which in this sector and for the year 1998 represented approximately 74% of the total costs. These cost refer principally to the consumption of degradable products, as ropes, the nets that hold the mussels in place, sticks, bags and other specific products necessary for working. Insofar, as maintenance is concerned, the repainting of boats, fuel costs, repairs to the mussel beds, etc (see Table I). Finally, given the options models offer a neutral-risk valuation it is not necessary to use a risk-adjusted tax rate but only the risk-free interest rate (source: Bank of Spain).

Table I
Operating Costs (year 1998).

costs	Pesetas	Euros
Raw material	170.654.400	1.025.653,601
Consumption degradable products	3.879.814.240	23.318.153,21
Other consumption	337.369.700	2.027.632,734
Maintenance costs	1.755.911.880	10.553.242,94
Society costs	550.000.000	3.305.566,574
Total	**6.693.750.220**	**40.470.653,9**

Source: García et al (2000).

5.2 Galician mussel sector valuation as an European call option.

This sections allows us to illustrate the solution obtained by using the real option model presented at section 2.3.

Although there exists tables for the accumulated probability distribution, N(.), in this study a polynomial approach as the one below is adopted. This is an approach for the distribution which is usually fairly exact to the fourth decimal.

$$N(x) = \begin{cases} 1 - N'(x)(a_1 z + a_2 z^2 + a_3 z^3 & when \quad x > 0 \\ 1 - N(-x) & when \quad x < 0 \end{cases},$$

$$\begin{aligned}
& where: \\
& z = \frac{1}{1 + gx}, \\
& g = 0.33267, \qquad\qquad (5.1) \\
& a_1 = 0{,}4361836, \\
& a_2 = -0.1201676, \\
& a_3 = 0.9372980, \\
& N'(x) = \frac{1}{\sqrt{2p}} e^{-\frac{x^2}{2}}.
\end{aligned}$$

The results of this illustration are given in the Table II:

Table II
Option value for the mussel exploitation in Galicia.

Year	h(T) (kg)	Cte(T) (euros/kg)	N(d1j)	N(d2j)	Option value (euros)	Option value (euros/kg)
1995	164.916.000	0,230	0,902	0,800	23.330.878	0,141
1996	216.905.000	0,181	0,940	0,821	42.729.799	0,197
1997	230.357.000	0,173	0,938	0,776	49.681.414	0,216
1998	220.198.000	0,184	0,926	0,709	48.815.814	0,222
1999	224.984.000	0,186	0,927	0,672	52.193.659	0,232
2000	250.000.000	0,173	0,938	0,669	61.899.750	0,247

Table II offers the numerical illustration that has been carried out for the years between 1995 and 2000, being the present time considered, t, January 1995. The evaluation in euros per kilogram of the mussel bed has increased in time, but at the beginning the variation tax is about 39,71%, and afterwards about 6,46%. The global value, in euros, suffered a slight decrease form 1997 to 1998 because that year the mussel sales were reduced.

5.2.1. Sensitivity Analysis.

One of the most important aspects of the options valuation is that it does not depend on price future probability estimations. This is true because these estimations are considered in both, the volatility estimation and the present resource price. Other important aspect is that the valuation does not depend on the drift rate, m but on the risk-free interest rate.

Given the importance, for the option valuation, that both the volatility and the risk-free rate represent, it is showed the option value sensitivity to this parameters in the Table III:

Table III
Option value sensitivity analysis to the volatility and the risk-free interest rate.

		1995	1996	1997	1998	1999	2000
	0,3	0,134	0,191	0,207	0,209	0,218	0,234
Volatility	**0,45**	0,141	0,197	0,216	0,227	0,232	0,247
	0,6	0,152	0,207	0,228	0,238	0,249	0,265
Risk-free	**0,04**	0,137	0,191	0,208	0,212	0,221	0,236
interest rate	**0,065**	0,141	0,197	0,216	0,222	0,232	0,247
	0,08	0,144	0,201	0,220	0,227	0.238	0,254

Euros per kilogram.

The Table III shows that the greater the volatility the greater the mussel exploitation value is met. That is, a greater uncertainty does not represent a loss in value but that value is generated on the basis of the future opportunities that said uncertainty generates.

On the other hand, it can be observed that the greater the risk-free interest rate the greater the value of the mussel exploitation obtained. In order to better understand this result given above, it can take the expression (2.3), where appears how the present value of the costs necessary to undertake the mussel activity decreases when the interest rate increases, but not the value of the income. On the other hand, as it is a risk-neutral valuation, the expected growth rate of the resource price grows with the risk-free interest rate, which would justify the result obtained.

5.2.2. The Option value and the Traditional Literature (DCF).

Figure 4
Option value and the traditional literature.

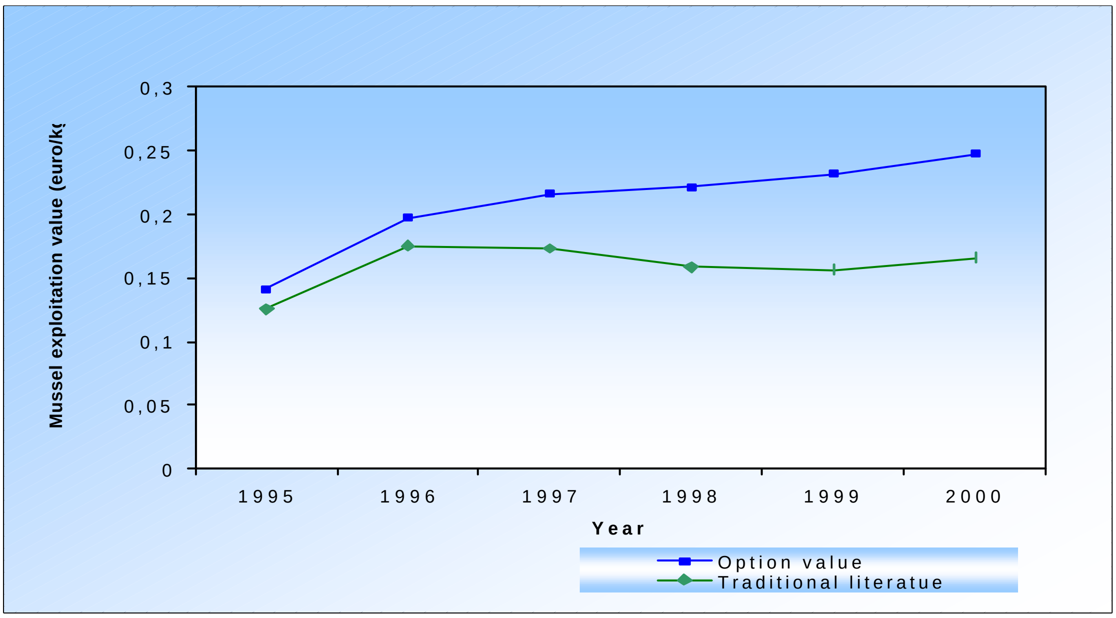
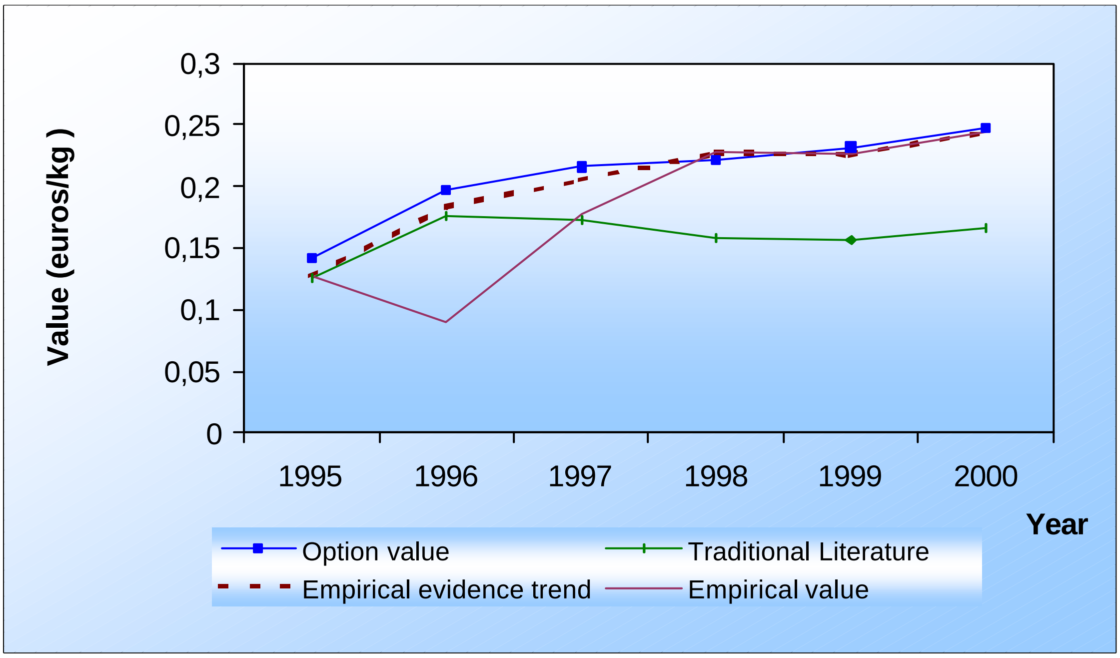


Figure 5
The option value and the empirical evidence.



The Figure 4 shows the value expressed in euros per Kg of the mussel exploitation obtained by using the option theory on the one hand (2.3) and by the traditional discount methods on the other. It would be emphasized that, for the different years analysed, the value that traditional studies provide is lower than that of the option theory, going so far as to undervalue the true value, that was generated in this sector, for the years 1998 to 2000. The difference between both values grows in time, that is, the further away the estimation date with respect to the present time, in which the decision-making takes place, the greater the difference between the values. Some writers, such as Amram and Kulatilaka (1999) have named this difference "*the management flexibility cone*".

The Figure 5 shows the difference between the theoretical model value and the empirical one. Firstly, it is convenient to note that in the year 1996 there was a significant price shock, the reason for which the option valuation moves further away from the real one. It should not be forgotten that the option evaluation model is based on the assumption the price describes a Brownian Geometrical process and, therefore, the model does not reflect sharp price changes. Thus, what really it is interested in order to establish comparisons is the trend of the empirical value.

For the years between 1995 and 1997, it is observed that the option value is higher the empirical one. However, the further away the estimation date, that is, for the years between 1997 and 2000, the option value is near and near to the empirical value.

5.2.3 Risk and Uncertainty. The Value at Risk of the mussel exploitation (VaR).

The uncertainty leads to risk, the prospect of gain or loss, and risk (or, more precisely, the risk of loss) is something that it must all come to terms with. Coming to terms with risk does not mean eliminating risk from our lives, which is clearly impossible; nor does it mean that we should do nothing about risks and accept consequent losses fatalistically. It means that *we must manage risk*.

Particularly, this section analyses the exploitation risk by using the Value at Risk (VaR) methodology. VaR refers to a particular amount of money, the maximum amount the manager is likely to lose over some period, at some specific confidence level.

Given the mussel exploitation has been valuated as a real option, the VaR of the exploitation is going to be calculated by using the very well-known *Delta-Gamma covertures*,[8] which permits us to obtain a risk approximation as following:

$$VeR(c) = \Delta V(dS) + \left(\frac{1}{2}\Gamma\right)^2 V(dS^2) + 2\left(\Delta\frac{1}{2}\Gamma\right)Cov(dS, dS^2). \qquad (5.2)$$

By considering the output price process:

$$VeR(dc) = \Delta V(dS) + \left(\frac{1}{2}\Gamma\right)^2 V(dS^2). \qquad (5.3)$$

Finally, an expression for the VaR is derived:

$$\begin{aligned} &VaR(dc) = Z\boldsymbol{a}\sqrt{\Delta^2 S^2 \boldsymbol{s}^2 + \frac{1}{2}(\Gamma S^2 \boldsymbol{s}^2)^2}, \\ &delta(\Delta) = \frac{\partial c}{\partial S}, \qquad (5.4) \\ &gama = \Gamma = \frac{\partial^2 c}{\partial S^2}. \end{aligned}$$

The Table IV shows both the Value at Risk and the sensitivity analysis of the mussel exploitation, given it has been valued like a real option.

[8] See Jorion (1997).

Table IV
Value at Risk (VaR) of the mussel exploitation.

		Sensitivity analysis				
Year	**VaR**	**delta**	**gamma**	**theta**	**rho**	**vega**
1995	0,235	0,902	0,007	-0,011	0,287	0,1
1996	0,243	0,94	0,003	-0,007	0,433	0,098
1997	0,2425	0,938	0,003	-0,006	0,552	0,123
1998	0,24	0,926	0,003	-0,005	0,669	0,162
1999	0,24	0,927	0,002	-0,005	0,75	0,18
2000	0,24	0,936	0,002	-0,005	0,725	0,163

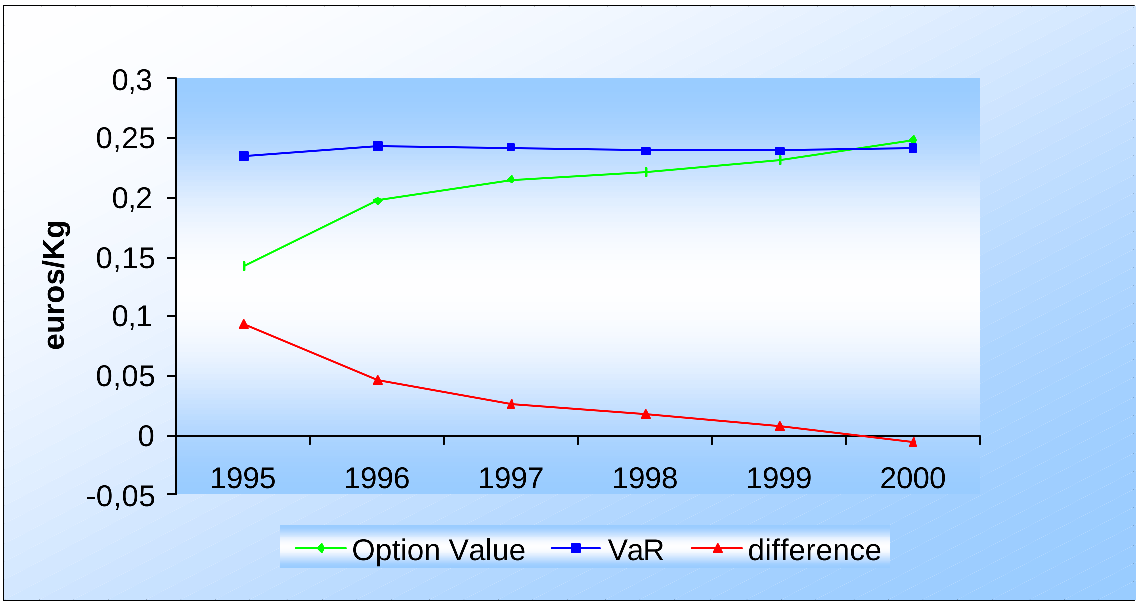
The obtained VaR for the mussel sector is over 0,24 euros / Kg between the years 1995 and 2000, but it does not mean the exploitation risk to be constant as it is going to explain below.

It would have been logical to think that the risk value would be equal to the option value. Notice, if mussel price going upwards there would be unlimited benefits, however, the losses are limited by the option value (the manager has the right but not the obligation to exercise the option).

Figure 6 shows that the VaR is higher than the option value, although both of them tend to converge the further away the estimation date is, that is, for years between 1998 and 2000. Thus, the exploitation risk is lower and lower in time.

Finally, the VaR sensitivity to time, risk-free interest rate, and volatility is analysed by using the very well-known *Greek letters*: *theta*, *rho* and *vega*. The *vega* rate is greater further away the estimation date, so the mussel value is the more and more sensitive to the price volatility. The same interpretation is derived for the risk-free interest rate by using the *rho* rate. Note, the theta rate is negative, that is, the smaller the temporary horizon to exercise the collection option, the lower the mussel exploitation value.

Figure 6
The Value at Risk and the Option Value.



5.3 Galician mussel sector valuation as an American call option.

This sections shows the American option value for the mussel exploitation obtained by using the expression (3.2). This model assumes the existence of positive Convenience Yields and, therefore, the European option value must be derived by using the expression (3.5).

Table V
European and American option values.

	k	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
European Option ***Value. (euros / Kg)***	***0***	0,141	0,197	0,216	0,222	0,232	0,247
	0,02	0,135	0,184	0,197	0,197	0,201	0,211
	0,04	0,129	0,172	0,179	0,175	0,174	0,179
American Option Value. (euros / Kg)	***0,02***	0,139	0,190	0,208	0,214	0,223	0,237

k: convenience yield.

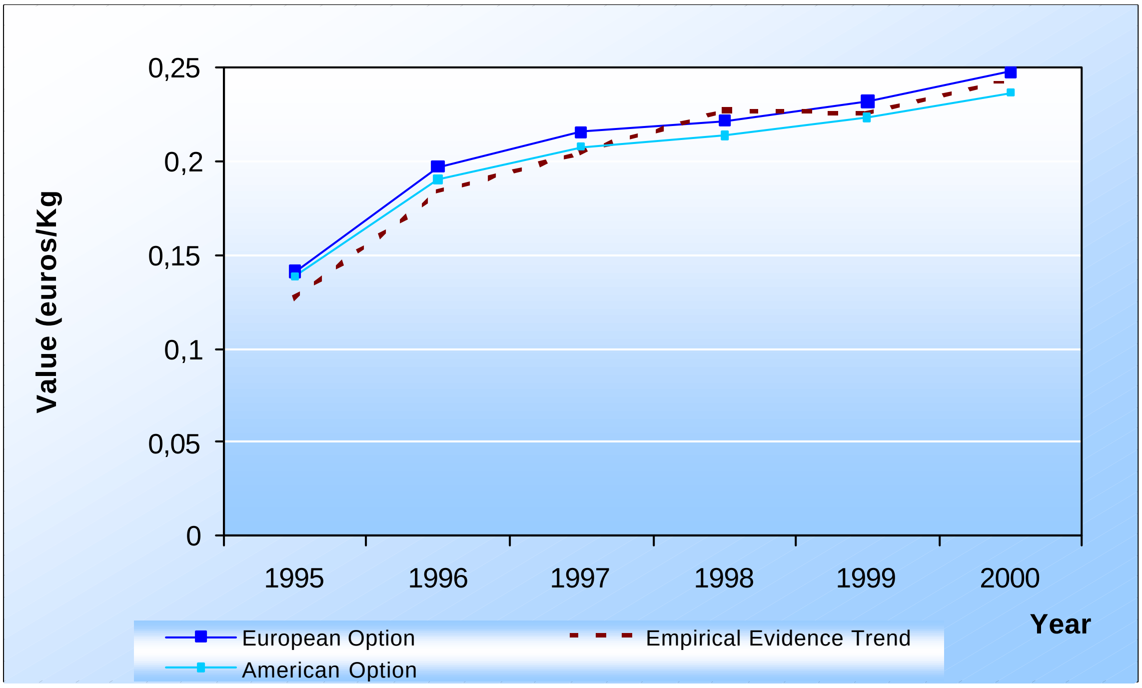
The Table V shows that the European option value (considering there exists convenience yields) is slightly lower than the value of the American option one. This is due to the fact that the American option allows the mussel farmed to be collected before the final date, that is, it is farmed with greater flexibility, it is considered the option of *Wait and See* and this has a value.

Table V also shows the introduction of convenience yields reduces the mussel exploitation value. Notice that greater convenience yield indicates a growth in expectations of a shortage of mussel. It can be observed that for the year 2000 the value reduction is about a 27%.

5.3.1 The Option Values and the Empirical Evidence.

If it is looked at Figure 7, the American option evaluations are more in keeping with the trend the sector has really experienced, which might be due to the fact this model considers and also adapts to a greater number of uncertainties and for it incorporates the additional valuation of the option of Wait and See.

Figure 7
The option values and the trend the mussel sector has experienced.

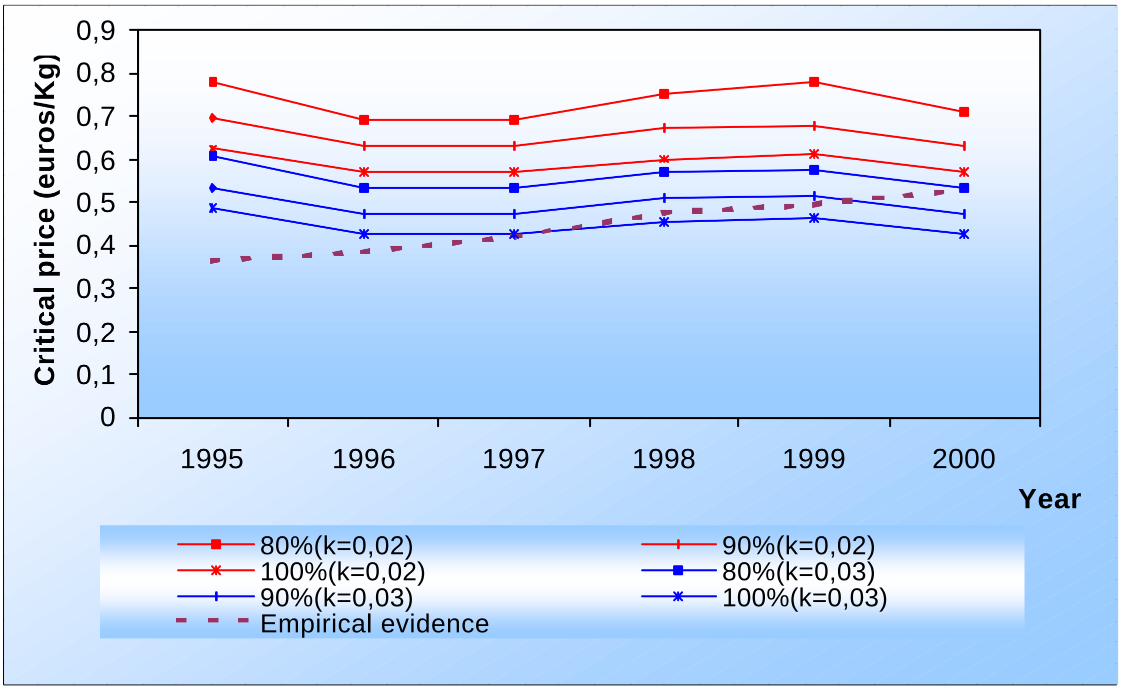


5.3.2 The critical prices.

This valuation model allows us to obtain mussel exploitation evaluations but at the same time to determine what the optimum resource exploitation policy is; that is, the critical price above which it is optimum to stop farming the mussel. It allows us to determine an optimum mussel rotation policy which changes according to each of the years.

Therefore, it is interesting to ponder a little further over the evaluation and analysis of said critical prices. They are obtained from an iteration process using the expression (3.4).

Figure 8
Critical prices.



In the Figure 8, it can be observed that the more the mussel collection date is brought forward (and the lesser, therefore, the volume collected), the higher the critical price is, and so, the lower the exploitation opportunities. This result would seem logical if we believe that the manager will be willing to relinquish a certain volume of mussel resource in favour of an increase in its price.

Finally, it is analysed the effect of the convenience yield on the critical price level. In the Figure 8, it can also see that, the greater the convenience yield (and, therefore, the greater the future mussel volume scarcity expectations) the lower the critical prices. The manager prefers to collect now the resource at a lower price not to be able to do it in the future (given the future scarcity possibilities).

5.3.3 ¿would it have been the smaller-sized mussel collection an optimal strategy?.

Given the real price series that were generated in the mussel sector in the years mentioned, in Figure 8 it can see how in 1998 and 1999 it would have been optimum to collect a volume of 90% of the farmed mussel early without having waited until the end of the period. In year 2000, this circumstance was repeated even for a volume of 80% of the resource. It is worth asking, then, if said policy might have been interesting given both the biological and economic conditions prevailing in said years in Galicia.

Spanish fresh mussel imports.

Given the result above, it is interesting to find out what the evolution of Spanish fresh mussel imports[9] have been like in order to know whether or not the policies of smaller-sized mussel collection could have been interesting for those years. Labarta and Corbacho (2002), basing their findings on ICEX and FAO statistics, observe that Spanish imports have been rising since 1996 and went from 3.090 Tm that year to 5.984 Tm in the year 2000 (see Figure 9).

Figure 9
Spanish fresh mussel imports.

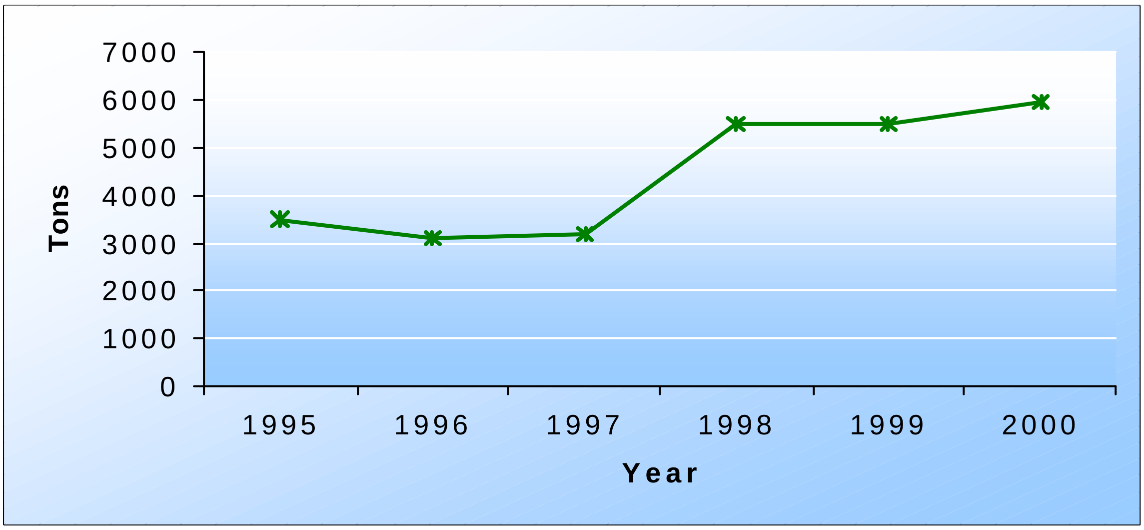


Figure 9 shows that the imports experienced a notable rise in 1998, maintaining their total amount until 2000. Labarta and Corbacho (2001) underline that these imports are important not so much for their tonnage but for the sudden growth they experience. Spain being the leading European producer, such figures are not important in terms of tonnage but, however, they could be indicative of market segments ignored by Spanish

[9] The main foreighn suppliers of fresh mussels are France and Ireland. Also beginning to be relevant, more on account of their quick growth than their tonnage, are imports from Greece, Denmark, The UK, Portugal, Holland and Chile.

production itself. In particular, empirical evidence shows us that, Galician, mussel sector could have taken up positions in other areas of the Spanish coastline which, required a smaller-sized mussel. Therefore, the need to develop all the market potential was not recognised.

Having analysed the real situation of the sector's imports briefly, it can be concluded that, for the years 1998-2000, as Figure 8 shows, collecting a smaller-sized mussel would have been an optimum policy, compatible, and necessary, even, with the sector in those years.

CONCLUSIONS

It is clear that the profitability of the sectors, specifically, the Galician mussel sector, has been affected in recent years by different circumstances to which it would be necessary to adapt and be aware of. Thus, the proposal would be to introduce some innovations relating to the evaluation of aquaculture plants which allow for the plants to increase their profitability or at least to be able to cope with possible losses. This is why in this study the Real Options Theory is extended to the evaluation of a natural renewable resource: an aquaculture plant. The use of this theory is preferred to traditional discount methods, as it involves an asset whose flow depends on two volatile variables, the price and the stock of the resource farmed. Several evaluation models have been taken into account, using both European call options (and introducing the option of temporarily stopping activity), and American call options (and introducing the option to wait and see). In the latter case, with American options, the model is capable of determining not only the value of the aquaculture plant but also the optimum resource exploitation policy, that is, the critical price under which the plant must be closed temporarily.

The main results, derived from the application to the mussel sector in Galicia, reveal that the option value is higher than that of the traditional discount methods. However it is a very risky sector because, the calculated option value is higher than the risk obtained, by meaning of the Value at Risk methodology; although the risk is lower and lower the further away the estimation date.

With respect to the optimal rotation policy, having analysed the obtained critical prices, it can be concluded that, for the years 1998-2000, collecting a smaller-sized mussel (so, being shorter the resource rotation time) would have been an optimum policy. In fact, this kind of policy would have been compatible, and necessary, even, with the sector in those years because, mussel sector could have taken up positions in other areas of Spanish coastline which required a smaller-sized mussel.

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