Socioeconomic analysis of the seaweed *Kappaphycus alvarezii* and mollusks (*Crassostrea gigas* and *Perna perna*) farming in Santa Catarina State, Southern Brazil

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Abstract

Planning and regulation of marine farms in Santa Catarina State, Southern Brazil, are designed to meet the interests of traditional communities. Public bidding documents of aquaculture sites elaborated from 2011 to 2013 provide information about the capacity of mariculture production in this state, which, together with the productivity indicators of *Kappaphycus alvarezii* farming in Santa Catarina, supply the necessary basic data for prospect and evaluation of the potentiality of three seaweed farming systems: monoculture of seaweed *K. alvarezii* (S1), biculture of *K.alvarezii* with oyster *Crassostrea gigas* (S2) and biculture of *K. alvarezii* with the mussel *Perna perna* (S3). Economic, financial and social evaluations conducted based on in these three systems show that among 720 aquaculture areas established in the state over 12 sites, 85% are designed to producers counting 969.45 ha, with an average of 1.57 ha/farmer. The seaweed production by the S1 system ammounts to 24,192 t/ha/yr while by S2 and S3, the outcome is 13,608 t/ha/yr, in addition to oyster (41,667 t/ha/yr) and mussels (40,000 t/ha/yr) production, respectively. All systems consider 3 annual production cycles of seaweed. Economic, financial and social indicators show that all three systems are profitable. However, the S2 system was two times higher in profit than the others, in all respects.

Keywords: *Kappaphycus alvarezii*. Mollusks. Economic, financial and social analysis.

1. Introduction

The State of Santa Catarina at the Southeast of Brazil was alone responsible in 2015 for 95% or 20,438 t of the cultivated bivalve mollusks production of the country (EPAGRI, 2016), ranking Brazil as the second major producer of the mollusks in Latin America, only under Chile which produced 253,307 t (FAO, 2014). The cultivation of mollusks in Santa Catarina became a commercially rewarding activity since 1990, providing an alternative source of employment and income to the local fishermen, hit as they were by the declining fishery (OLIVEIRA NETO, 1995; EPAGRI, 2014). In recent years, this activity was recognized by the Brazilian government and left the informality 21 years late through policies as the Local Mariculture Development Plan (Plano Local de Desenvolvimento da Maricultura – PLDM) which involves legislation for identification and delimitation of marine and estaurine aquaculture parks (AP) and zones or privileged areas for local communities (SEAP, 2005; 2007; SUPLICY et al., 2015). Twelve PLDMs were approved in Santa Catarina, one for each municipality of the State, inclosing altogether 21 APs, which were divided in their turn into aquaculture areas (AA) (NOVAES et al., 2010; SUPLICY et al., 2015). The APs alloted among the 12 municipalities comprise 573 free AAs (free concessions of the area to the producer) and 46 paid AAs (concession to the producer through payment) (MPA, 2013a, 2013b; DOU, 2011a, 2011b; MPA, 2011a, 2011b). This planning solved the legal uncertainities inherent therefore to the aquaculture, opening access since 2011 to financial credits and other public policies intended to promote the production. These uncertainities had limited the production growth up to that time, reducing the number of producers from 895 in 2005 to 589 in 2013 (EPAGRI, 2014).

But other elements were also responsible for this reduction, such as the dependence of the mussel seeds supply on environmental conditions, not mechanized artisanal production system, the monoculture and the resulting lack of flexibility to deal with the enviroment adversities and market conditions. An example is the *Perna perna* mussel's production, which fell from 21,017 t in 2012 to 16,147 t in 2013 because of the successive low capture of the seeds through these years (EPAGRI, 2014). Investigations are made around the world in search of technological solutions for mariculture diversification which could strengthen that activity, as for instance the utilization of the integrated multi-trophic cultivations, which brings such benefits as reduction of the handling process, optimization of the marine space, increase of production and productivity and consequently, of the marine farms profitability (FAO, 2009; CHAVEZ-CROOKER; OBREQUE-CONTRERAS, 2010; CHOPIN, 2010; ABREU et al., 2011; GUERRERO; CREMADES, 2012; KINGLER; NAYLOR, 2012; HAN, et al., 2013; KANG et al., 2013). Among the pioneering experimental works, it is possible to point out those performed by Canada, Chile, Israel, China, and more recently Scotland, Ireland, Spain, Portugal, France, Turkey, Norway Mexico, and now Brazil (FAO, 2009; GUERRERO; CREMADES, 2012; REN, et al., 2012). Relevant in those works are the seaweeds, present as they are in all combinations of multi-trophic cultivations, allowing the highest productivity among all photosynthetic organisms and possibility of production with a low cost technology. Nightly consumption of the oxigen by the seaweed are much lower than their daily production, and this in another advantage. Some species can produce up to 12 times more oxigen than it breathes during night.

According to data supplied by FAO (2016), seaweed production ranked second in aquaculture in 2014, with 27,3 million tons and yelding US$ 5,6 billion in farm gate value, surpassed only by the freshwater fishes' production. The *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva (Rhodophyta, Gigartinales) and the *Eucheuma* J. Agardh were resposible for the major part of the production (34%), or about 8.3 million tons. Both species are commercially relevant, being the main raw material for the carragenan industry, a colloid utilized as thickener and stabilizer in several industry branches (BIXLER; PORSE, 2011; FAO, 2012). Market analysts forecast an US$ 7.9 billion hydrocolloid market movement by 2019 (HOLTZ, 2015).

In spite of robust world trade, culture techniques are simple and artisanal, based on the environment´s characteristics and on the traditional low-income population. Implanting is undertaken by women and administered by commercial investors (SALAYO *et al*., 2012; YARISH; PEREIRA, 2008; ASK; AZANZA, 2002).

Due to this family profile, economic (plantation and production costs) and financial studies are not performed by enterprisers but by technicians, researchers, investors and funding agents. Comparisons are difficult due to the diversity in crop techniques, great variations in infrastructure and production costs (labor, inputs and others) and operational scales (VALDERRAMA et al., 2015).

Comparative economic analysis of cultivation methods are performed by researchers from the Philippines, Tanzania, Indonesia and others, most of whom indicate the superiority of floating cultures when compared to sea bottom ones (VALDERRAMA et al., 2015; MSUYA et al., 2007).

In general, world seaweed farming requiring low initial capital investment, simple production technology, growout cycles short and attractive prices, providing high and rapid return on investment. For these reasons, international agencies began promoting seaweed farming in Indonesia and neighboring countries to improve the social and economic conditions of marginalized coastal populations (VALDERRAMA et al., 2015).

Kappaphycus alvarezii is not found in Brazilian coast. It was first experimentally introduced on the coast of the state of São Paulo, in 1995, due to demands worldwide and by Brazil on carrageenan. The aim was to make Brazil self-sufficient in the production of the colloid (Oliveira et al., 2009).

Later in Rio de Janeiro, Rio Grande do Norte, Paraíba and Santa Catarina. However, the cultivation was licensed by environmental agencies and documented in scientific publications only in São Paulo, Rio de Janeiro and Santa Catarina (PAULA et al., 1999; PEREIRA et al., 2004; HAYASHI et al., 2011; REIS et al., 2016). The introduction in Southern Brazil was done experimentally in 2008 at Sambaqui Beach, Florianópolis, Santa Catarina, in order to evaluate the technical, economic and environmental viability of its cultivation in this region. After 4 years' study, the growth rates observed principally between spring and autumn were similar to those of commercial strains and of the carragenans showed quality by comercial standards (HAYASHI et al., 2011). The macroalga *Kappaphycus alvarezii* is being offered to mollusk producers of Santa Catarina as a technological solution in diversification and integration of mollusk and alga cultures, with the exploitation of a second species. This would increase productivity and profits of sea farms and attend to the internal market of carrageenan. In 2015, Brazil imported 1,836 tons of carrageenan at the cost of 16 million (REIS et al., 2016).

Therefore, the purpose of this paper is to prospect and evaluate the *Kappaphycus alvarezii* cultivation potentiality, in monocultures as well as in integrated cultivations with molluscs at Santa Catarina's aquaculture parks, considering the relevance of this species and the legal conditions of these parks as well as their capacity. This evaluation was performed taking into analysis their production and productivity, deployment costs, as well as economic and financial viability. Mechanized cultivation systems are proposed, as they allow better safety conditions, higher performance and productivity for the workers.

2. Materials and Methods

The area under study is shown in the Figure 1. This is a protected coastal area delimited by the parallels 26º2'52" and 28º41'43" South and the meridians 48º22'26" and 48º59'59" West, which harbors the biggest concentration of the marine farms of Brazil.

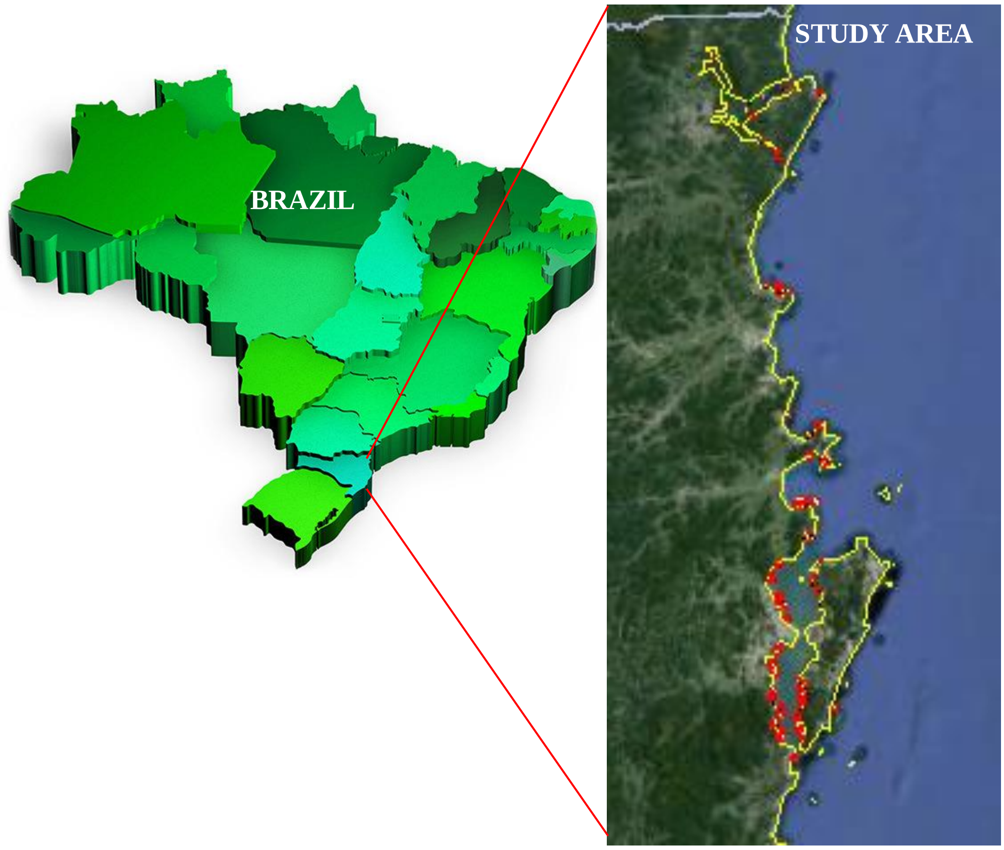

Figure 1: Marine farms of Santa Catarina, highlighted in red, from the extreme North (São Francisco) to the South Center (Palhoça).

2.1. Aquaculture parks of Santa Catarina

The data base of this study comprising: production capacity and productivity of the Aquaculture Parks (PA) and their respective Aquaculture Areas (AA), number of bid winner areas, number of areas still available and size of the areas in hectare (Table 1), was obtained from six bidding documents. Municipalities were visited so as to identify among the bid winners those producers already at work. Municipal associations of producers and extension experts who gave assistance to the producers were interviewed for that purpose.

2.2. Cultivation systems

The following technical indicators of *K. alvarezii* production in Santa Catarina were obtained from Hayashi et al. (2011): three cultivation cycles (of 36, 42 and 97 days) per year between spring and autunm, growth rates varying from 0.32% per day (winter) to 5.12% per day (summer), 1.15 kg/m initial seedlings density in tubular nets and 7 kg/m final harvest density. The cultivation potential of this seaweed by three systems, namely: monoculture (S1), biculture with oysters (S2) and biculture with mussels (S3) were forecasted by these and other pertinent data of Santa Catarina aquaculture parks. Technical indicators of oysters production (41,667 t/ha/yr) and of mussels production (40,000 t/ha/yr), and other information regarding implantation and production cost composition were based on the production characteristics of the marine farms similar to those of Santa Catarina, as well as on studies performed on those aquaculture properties (SANTA CATARINA, 2003, 2004). Commercial prices of the products were based on the average prices practiced in 2015, in the Santa Catarina State (EPAGRI, 2015). Production technology of the Santa Catarina mussels makes use basically of floating cultivation structures with long lines, with 100 m length and 10 m spacing between long lines. Lantern nets of oysters (*Crassostrea gigas*) or mussels (*Perna perna*) ropes are hanged in long line spaced 1 m from each other as for the oysters lantern nets or 0.5 m as for the mussels ropes. The oysters are planted in 5 storeys in average and the mussels in polyetylene tubular nets. Seaweed cultivation is performed in floating rafts constructed with longline PVC tubes, measuring 3 m width and 100 m length. The rafts are formed by 18 blocks having 5.5 m length where the seaweed planted in tubular nettings are cultivated the same way as for mussels, displayed horizontally at the surface at 0.4 m spacing between tubular nets. The S1 system is dimensionally determined by 16 algae cultivation rafts, whereas the S2 and S3 systems by 10 long lines for mollusks cultivation having 9 seaweed cultivation rafts inserted in between.

The same operation principles applied to the mussel extraction were used in the development of seaweed harverster. Similarly, the tubular nets utilized in monocultures and integrated cultures are the same of those employed in mussel's cultivation. This is done in Brazil for the *Kappahycus alvarezii* cultivation since they provide better protection to the algae, favouring besides its plantation and harvest (HAYASHI et al., 2011; REIS et al., 2015).

2.3. Production and the State gross revenue

From seaweed and mollusks productivity data by hectare, an estimation was made of the production and the gross revenue for the Santa Catarina AP, considering two conditions: intalled capacity (AAs already bidden = 969.45 ha) and total capacity (bidden AAs + AAs in bidding process = 1,178.10 ha).

2.4. Implantation and production costs

2.4.1. Implantation costs

Economic resources necessary for the purchase and assembling of the seaweed monoculture or seaweed and mussels biculture were evaluated as implantation costs, considering: a)10,000 m^2 (ha) AA obtained through public bidding and granted by the federal government; b) cultivation structure itself installed in the aquaculture space in compliance to the delimited technical specifications (SANTA CATARINA, 2003); c) investments realized in mechanics and logistics to operationalize the production of the seaweed and mollusks, dimensioned in accordance to the size of the production units in the 3 proposed systems, S1, S2 and S3.

2.4.2. Production costs

The identification of the most profitable production system is made on the unit and total cost evaluation per 1 ha aquaculture area. The total cost estimation considers all fixed and variable costs related to the proposed three cultivation systems. The unit cost is obtained dividing the total cost by the volume in kg produced by each culture. Sixteen seaweed rafts were utilized in S1 and 9 rafts in the S2 and S3 systems. The reduction of the seaweed rafts in S2 and S3 relatively to S1 produced in consequence a reduction also in the quantity of the used inputs in 1:0.5625 proportion, or 56.25%. This proportionality is considered to evaluate the quantity of the equipment, the production and the implantation costs.

The total cost is related to the sum of the expenses and the costs, fixed and variable. The variable costs evaluation considered: a) for the oysters, a productive cycle of 12 months (March to February), with planting of 1 million seeds distributed in two periods (winter and summer), and a survival rate of 50%; b) for mussels, a productive cycle of 12 months (March to February), with planting of 6.0 t seeds in a single period and a yield of 66.7%, or in other words, a net production of 40 t mussels/ha; c) for seaweed, 3 yearly cultivation cycles, with seedlings plantation density of 1.15 kg/m and wet seaweed harvest density of 7 kg/m.

The variable costs are composed by: a) inputs, including expenses related to seeds, nets, cables, protective clothings, etc.; b) labor employed for hanling operations expressed in man-day prices as practiced by the marine farms in Santa Catarina; c) other expenses; d) financial costs; e) commercialization expenses; and f) mechanical services for S1, S2 and S3. For the mechanical costs evaluation, the machine-hour (MH) cost, based in Capello et al. (2010), is the total of the machine maintenance cost (MC) and the fuel cost (FC):

$$MH = MC + FC$$

The maintenance cost (MC) takes into account the average maintenance cost rate throughout the machine´s useful life, based in its initial purchase value, as calculated by the expression:

$$MC = \frac{(ViM \times TxmM)}{VuM}$$

Where ViM = value of the brand new machine (US$); TxmM = machine maintenance cost rate (%) and VuM = machine´s useful life (hours). The maintenance cost rates of the utilized machines considered in this work amount to 80% of their purchase price in brand new conditions. This means that a mollusk washer machine priced US$ 4,840.00 will have an estimated maintenance cost of 80% of this value throughout its 2,000 hours useful life. The fuel cost (FC) estimation is made taking into account the machine power in horse power (HP), its efficiency in litters per hour (C) and the price of the diesel oil (PrD)

$$FC = HP \times C \times PrD$$

The “other expenses” are related to those not included under other titles. One per cent of the expenses owing to input, manpower and mechanical services are reserved to those other expenses. Financial costs consider 4% yearly interest established by the Brazilian Financing Plan for family farming, on working capital (variable cost). Under the title of commercialization expenses are included the Social Security expenses incidental on the value of products commercialized by rural producers invoice (2.3%), which is a compulsory document accompanying either the sale or the transportation of any agricultural and livestock products. Fixed costs estimation considers: a) maintenance of the installations, b) depreciation of equipment and machines, c) taxes and interests and d) fixed capital reward. The depreciation, accounting reserve for the equipment and machines replacement, is calculated by the expression:

$$D = \frac{(Vn - Vs)}{Vu}$$

Where D = depreciation value, Vn = price of the good in brand new condition, Vs = price of the scrap after losing the original function (10% of the new state), Vu = useful life in years (SANTA CATARINA, 2004).

3. Economic, financial and social analysis

Economic analysis was performed to evaluate the profitability, the net profit and the return of the invested capital in the three proposed systems. Results were extracted from previous implantation and production cost analysis (SANTA CATARINA, 2003, 2004). Financial analysis was performed to evaluate the short, medium and long-term financial viability of the proposed systems. In this regard, a cash flow related to the period was carried out to determine the economic indicators that attest the feasibility of the installation. In addition, one can select the Discounted Cash Flow (DCF) valuation, which relates the value of an asset to the present value of the future cash flows related to that asset (LOPES SILVA, D. et al., 2014).

The net present value method together with the internal return rate and payback methods are considered more consolidated methods for economic viability analysis (VERGARA, et al., 2017; GITMAN, 2003). The cost-benefit index (C / B) or profitability index (IL), as a risk measure, is also considered relevant for feasibility analysis (VERGARA, et al., 2017). In the present article, the first three techniques are employed.

The net present value (NPV) is one of the most used instruments to evaluate capital investment alternatives. It reflects the investment attractiveness (in monetary values) measured by the difference between the present value of the cash inflows and the present value of the cash outflows, at a given discount rate. The investment greater than or equal to zero is considered attractive, that is, if the present value is positive, it means that the project is feasible (CASAROTTO FILHO, KOPITTKE, 2010; KASSAI et al., 2000). The choice between the various profitable and comparable variants of the same cultivation system (mutually exclusive alternatives) will fall, according to this criterion, on the one with the highest NPV (CASAROTTO FILHO, KOPITTKE, 2010; GALESNE et al., 1999) . The NPV is obtained by Equation 1:

$$NPV = - I + \sum_{t=1}^{n} + \frac{CF_t}{(1+K)^t} + \frac{RV_t}{(1+K)^t} \quad (1)$$

Where:

NPV = net present value;

CF_t = foreseen flow of cash inflows in each project life time, t = 1, 2, .., n;

n = number of evaluation periods;

I_0 = inicial investiment;

K = interest rate or cost of capital or minimum rate of attractiveness;

VR = residual value of the project.

The internal return rate (IRR) represents the average profitability of the money used in the project over its duration. The IRR is the rate that makes the present value of future profits equivalent to the expenses incurred with the project, thus characterizing the remuneration rate of the invested capital; it is the rate that makes null the NPV of the investment cash flow. The investment that presents IRR> MAT (Minimum atractivity rate), which is the minimum rate to be reached in a given project, is considered profitable; otherwise, it can be rejected (COHEN, FRANCO, 2000). Alternatively, two other interpretations are possible: the IRR represents the value of the capital cost that makes the NPV become zero, a rate that remunerates the amount invested in the project, or the discount rate that equals the NPV of the investment to zero (WOILER; MATHIAS, 2014; BRUNI; FAMÁ, 2012); and the IRR represents the rate that will return equivalent to the present value of future profits to the expenditures of the project, characterizing the rate of remuneration of invested capital (PONCIANO et al., 2004).

Where: (2)

$$I + \sum_{t=1}^{n} \frac{I_t}{(1+K)^t} = \sum_{t=1}^{n} \frac{CF_t}{(1+K)^t}$$

I_0 = inicial investiment;

I_t = amounts of subsequent investments;

K = internal return rate (IRR);

n = number of evaluation periods;

CF_t = foreseen flow of cash inflows in each project life time, t = 1, 2, ..,n.

The payback of the investment indicates when the investment will be recovered, that is, how long it will take to the money invested return. It is performed by analyzing the cash flow and when the investments (negative flows) cancel out with the cash inflows (revenues), then one will have the payback period. Since simple payback does not consider the cost of capital, the sum of the investment balances can be made on the basis of nominal values (BRUNI; FAMÁ, 2003).

The payback is used together with the NPV and IRR methods in the decision making process to minimize the risks of using a method that does not take into account the time factor (LINDEMEYER, 2008).

Social analysis is performed to evaluate the amount of employment generated by the three proposed systems, with fixed and contracted man power, based on implantation and production cost analysis with the manpower used in the marine cultivations and in handling stages, expressed in man-days.

4. Results and Discussion

4.1. Aquaculture parks of Santa Catarina

Despite the State of Santa Catarina leads the ranking of major national mollusk producers, with a production of 20,438 t in 2015 (EPAGRI, 2016), results of the present work show that the Santa Catarina's APs potentiality is 71,256.9 t/yr. Therefore, only 26.78% of this capacity is being explored, limited as is mainly by the fragile and informal trade in oysters, by the natural capture of the mussels seeds subjected to environmental conditions, and also, by the adopted cultivation system based in monocultures (EPAGRI, 2014). Regarding this cultivation potentiality of Santa Catarina, 720 AA were offered in public bids, 85.97% of them summing altogether 969.45 ha destinated to marine farmers, or 1.57 ha per farmer in average (Table 1). These marine farms are distributed in 21 APs spread among the traditional local communities at the State coast over 12 municipalities (Fig. 1), explored by 572 producer families of *Crassostrea gigas* oysters and *Perna perna* mussels (EPAGRI, 2015).

Table 1: Numbers of potential production of aquacultures parks (AP) and their respective aquacultures areas from the coast of Santa Catarina state, Brazil.

Aquaculture Parks of Santa Catarina State	
N° of AP	26
N° of bid AP	21
N° of AA	720
N° of bid AA	619
N° of available AA	101
Occupance rate of AA (%)	85.97
Total size AA (ha)	1,178.71
Total size bid AA (ha)	969.45
Occupance rate (%)	82.25
Total potential production (t/ha)	71,256.90

Total bid production (t/ha)	57,967.50
Available potential production (%)	81.4

As a public policy to promote economic and social development, 93.02% of the marine farms were reserved for the low-income population at no charge for the producers, the same way as done abroad where the marine farms near the coast were conceived so as to boost up the traditional communities' development (SALAYO et al., 2012; FAO, 2013; NARAYANAKUMAR; KRISHNAN, 2013; MSUYA, 2014).

Among the 720 areas offered in bids only 101 (14.03%) remained without winner, therefore still available. As for the size, Santa Catarina bidded 969.65 ha having an estimated production of 57,967.50 t per year. If the 101 still available areas are included, the total would reach 1,178.94 ha and a production of 71,256.96 t per year of mollusks (Table 1).

The marine farms are characteristically small properties having in average 1.57 ha. They were conceived on the State's agrarian structure, composed mostly by small familiar rural properties, which makes 87% out of the total 193 thousand rural properties (ESTEVAN; MIOR, 2014). These small rural family properties explore several species which grant good returns. Diversification is a way to boost the productivity and the income of the marine farms (BARRINGTON et al., 2010; REN et al., 2012). Considering the technical and environmental potentiality presented by *Kappaphycus alvarezii* in Southern Brazil, and also, that the country is an importer of the carrageenan, this species becomes an outstanding element of the State marine culture diversification proposal (HAYASHI et al., 2011; MDIC, 2014).

4.2. Cultivation systems

The monoculture system was planned so as to occupy at most 16 cultivation rafts per hectare composed each one of 18 squares. The rafts are spaced 3 m each other so as to allow the circulation of the boats. The cultivation lines are spaced 0.4 m each other. Systems of cultivation in rafts are largely employed in India, Mexico and Phillipine Islands in deeper areas. Plantation spacement is 1 m between cultivation lines in off-bottom system as well as in floating system (FAO, 2013; VALDERRAMA et al., 2015). This spacement in Brazil is 0.4 m, which gives better productivity. Besides, the plantation density is also higher (1.15 kg/m) which assures a 24.19 t dried seaweed productivity in S1 (with 11.5 km cultivation line – Table 2) as compared to 12.65 t in Indonesia, and 13.6 t in S2 and S3 (with 6.5 km cultivation line – Table 3) as compared to 7.15 t in Indonesia. Comparing in another scale, the 2.1 kg/m per year productivity verified in S1, S2 and S3 is found within the parameters set by the world main producers, such as Indonesia (1.1 kg/m/yr), Philippines (1.43 kg/m/yr), Solomon Islands (5.43 kg/m/yr), and Mexico (5.38 kg/m/yr) (VALDERRAMA et al., 2015). Existing differences of productivity may be related to climatological factors, to the period of cultivation, to plantation density, to the quality of seedlings, to handling, to production scale and to such diseases as "ice-ice" (VALDERRAMA *et al*., 2015).

Each square has 8 cultivation ropes made by tubular nets. Twenty percent of the harvested biomass is reserved for replanting resulting in a productivity of 64.51 t/ha per cultivation cycle for wet seaweed or 8.68 t/ha per cycle for dry seaweed (24.19 t/ha/yr) (Table 2).

Tabela 2: *Kappaphycus alvarezii* productivity indicators grown in monoculture system for 1 hectare area.

Nº of floating rafts (99 m length x 3m width)	16
Nº of squares (5.5 m length x 3m width)	18
Nº cultivation ropes (CR)/square	8
Length of CR (m)	5
Total of CR (m/ha)	11,520
Wet algae produtivity (kg/m)	7 *
Biomass harvest cycle (t/ha/cycle)	80.64
Demand explants (20%)	16.13
Wet algae produtivity (t/ha/cycle)	64.51
Dry algae produtivity (35% humidity)	8:1**
Harvest yield (t/ha/cycle)	8.06
Anual cultive cycles	3
Dry algae produtivity (t/ha/yr)	24.19

*** (HAYASHI et al., 2011)**
**** (FARIA et al., 2013)**

In biculture system with oysters or mussels, the seaweed cultivation rafts were designed to be disposed in a layout interspersed with 10 long-lines/ha generally utilized for the cultivation of mollusks, thus reducing the quantity of rafts from 16 to 9 and in consequence, the seaweed productivity to 45.36 t/ha/cycle or 13.61 t/ha/yr (Table 3).

Table 3: *Kappaphycus alvarezii* productivity indicators grown in biculture system with oysters or mussels to 1 hectare of area.

Nº of floating rafts (99 m length x 3m width)	9
Nº of squares (5.5 m length x 3m width)	18
Nº cultivation ropes (CR)/square	8
Length of CR (m)	5
Total of CR (m/ha)	6,480
Wet algae produtivity (kg/m)	7 *

Biomass harvest cycle (t/ha/cycle)	45.36
Demand explants (20%)	9.07
Wet algae produtivity (t/ha/cycles)	36.29
Dry algae produtivity (35% humidity)	8:1 **
Harvest yield (t/ha/cycles)	4.54
Anual cultive cycles	3
Dry algae produtivity (t/ha/yr)	13.61

*** (HAYASHI et al., 2011)**
**** (FARIA et al., 2013)**

4.3. Production and State gross revenue

Production and gross revenue regarding the 3 proposed cultivation systems S1, S2 and S3 are calculated from data supplied by Tables 2 and 3. The gross revenue resulted higher in the biculture system with oysters, followed by the biculture with mussels and monoculture of the algae (Table 4).

Table 4: Productivity and gross income by hectare/year in monoculture systems (S1), biculture seaweed and oysters (S2) and biculture algae and mussels (S3) based on the average price of world trade.

Sistems cultivation	Productivity (t/ha/yr)	Cost	Annual income (US$)	
		(US$/kg)	Species/ha	Systems/ha
S1	24.192	1.5	36,288.00	36,288.00
S2	13.608	1.5	20,412.00	150,027.47
	41.677	3.11	129,615.470	
S3	13.608	1.5	20,412.00	76,412.00
	40.000	1.4	56,000.00	

Integrated cultivations showed better productivities (Tables 4 and 5). Table 5 shows the production capacity of the Santa Catarina's APs bidded areas, where the biculture with oysters stands out with highest productivity, followed by biculture with mussels and monoculture of the algae. The merits of integrated cultivation regarding higher mollusks productivity were also verified by Chopin (2010); Kingler and Naylor (2012) and Han et al. (2013).

Table 5: Productivity, production and gross revenue of the AA from state, considering the installed capacity (bid areas) and the total capacity from monoculture systems (S1), biculture seaweed and oysters (S2) and biculture seaweed and mussels (S3), based on the average mollusks price practiced in study area and the international average price for dry seaweed.

AA – Installed Capacity (969.45ha)

Systems cultivation	Productivity (t/ha/yr)	State Production (t/yr)		State income (US$)		
		Species	Systems	Cost US$/kg	Product	Total
S1	24.192	23,452.93	23,452.93	1.50	35,179,401.60	35,179,401.60
S2	13.608	13,192.28	53,586.35	1.50	19,788,413.40	145,413,980.90
	41.667	40,394.07		3.11	125,625,567.50	
S3	13.608	13,192.28	51,970.28	1.50	19,788,413.40	74,077,613.40
	40.000	38,778.00		1.40	54,289,200.00	

AA – Total Capacity (1,178.1ha)

Systems cultivation	Productivity (t/ha/yr)	State Production (t/yr)		State income (US$)		
		Species	Systems	Cost US$/kg	Product	Total
S1	24.192	28,500.60	28,500.60	1.50	42,750,892.80	42,750,892.80
S2	13.608	16,031.58	65,119.48	1.50	24,047,377.20	176,710,723.50
	41.667	49,087.89		3.11	152,663,346.30	
S3	13.608	16,031.58	63,155.58	1.50	24,047,377.20	90,020,977.20
	40.000	47,124.00		1.40	65,973,600.00	

The productivity of *K. alvarezii* regarding the proposed systems can reach in three cultivation cycles 24.19 t/ha per year of dry seaweeds in monoculture system and 13.61 t/ha/yr in biculture systems, in addition to the oysters production (41.67 t/ha/yr) and mussels (40.00 t/ha/yr) (Table 5). In Latin America, Mexico presented diversified productivity varying from 27 t/ha/yr to 54 t/ha/yr in 4 cultivation cycles. In Indonesia, with floating cultivation systems, the productivities varied from 6 t/ha/yr (Sulawesi) to 11.4 t/ha/yr (Nusa Tenggara Timur), and in Zamboanga, Philippines, 31.5 t/ha/yr (FAO, 2013; HURTADO et al., 2013). In Solomon Islands, the productivity of the off-bottom cultivation systems varies from 3.83 t/km to 5.43 t/km, while in Santa Catarina is found 2.09 t/km in floating system (FAO, 2013). Based on the results of the present study, Santa Catarina production of the bidded areas can reach 23,452.93 t/yr in monoculture system and 13,192.28 t/yr in biculture system. The monoculture system production amounts respectively to 28% and 38% of those of the major *Kappaphycus alvarezii* producers: Indonesia (85,000 t/yr) and Phillipines (61,000 t/yr) (BIXLER; PORSE, 2011). Taking into account the fact that this activity has not been consolidated in Brazil, this performance can be considered expressive for one Brazilian State. In 2000, Indonesia produced 27,000 t/yr. Santa Catarina can start comercial cultivations producing at least 49% of this amount in biculture system. Studies in Santa Catarina identified 3 cultivation cycles in careful and conservative evaluation, but once the comercial cultivations are established, we believe it will be possible to reach 5 cultivation cycles per year, as in countries situated in higher latitudes such as for example India, with four to six 45 days cycles per year, Mexico with four 60 days cycles per year and Phillipines with five 45 days cycles per year (FAO, 2013).

State gross revenue of the bidded areas (969.45 ha) was derived from the State production (Table 5) and mollusks average prices as practiced in study area, and algae prices in the international market (Table 4), where S2 presented the highest revenue followed by S3 and S1.

Considering the whole production potentiality of the Santa Catarina's AP (1,178.1 ha), the macroalgae, oysters and mussels production and the gross revenue increases 21.52% in S1, S2 and S3 (Table 5).

4.4. Implantation and production costs

Table 6 shows the results of implantation costs. It is possible to see that S2 required higher investment, followed by S3 and S1. The investments can be financed at low interest (5.5% to 7.5% per year) by government banks through credit lines opened to small and medium rural producers (BNDES, 2015; MDA, 2015). Almost 100% of the credits granted for fishermen and marine farmers were made through public financing in Santa Catarina. In the Phillipines, the government responds for only 40% of the financial incentives granted to the producers. The remaining is private financing (FAO, 2013). Public and private financial incentives are practiced also by other countries, as for example, Malaysia and Indonesia (NEISH, 2004).

The implantation cost of seaweed monoculture (S1) was US$ 70,365.39/ha. But excluding however the costs of machines and equipment, this cost becomes US$ 21,200.87/ha, approaching the cost in Yucatan Peninsula, Mexico (US$ 13,889.00/ha) for implantation of floating system not mechanized (FAO, 2013; VALDERRAMA et al., 2015) and that of Chile for implantation of *Gracilaria* farms not mechanized (US$ 13,587.00/ha) (MARTINEZ, 1990). Table 6 shows that the item machines and equipment takes 70% (S1), 81% (S3) and 79% (S3) of the implantation cost. Machines and equipment cost was responsible for most part of the implantation cost in Indonesia, Mexico, Philippines, India, Tanzania and principally, Solomon Islands, reaching as much as 97% of the total farm investment (VALDERRAMA et al., 2015).

Table 6: Implementation costs for 1 ha in the three culture systems (S1, S2 and S3).

Components	S1	S2	S3
Machines and equipments (US$)	49.164,52	96.935,70	88.138,13
Services of deployment (US$)	4.026,96	5.467,87	5.815,70
Infrastructure handling (US$)	17.173,91	17.173,91	17.173,91
Total	**70.365,39**	**119.577,48**	**111.127,74**

4.5. Economic, financial and social analysis

Table 7 shows production cost economic data. It shows that the gross revenue follows the hierarchical values of implantation costs, where S2 reveals the highest income, followed by S3 and S1. In S1, the production variable cost was US$ 16,934.40/ha/yr considering 3 productive cycles. However, expenses related to labor took only 4.5% of the total, the remaining being those related to inputs, mechanical services and others. The production variable cost in the Yucatan Penninsula reached US$ 1,931.00 per cycle, or US$ 5,793.00 for 3 cycles, where 78% of the total was spent to hire permanent employees, or 65.79% more than in S1 (FAO, 2013). In the Phillipines, the variable cost can reach US$ 5,964 in 3 cultivation cycles (FAO, 2013). The three proposed systems are mechanized and this burdens the invested capital, but mechanization is fundamental in order to increase productivity and reduce the labor costs.

Table 7: Economical datas from production costs for 1 ha/ano, in the three culture systems (S1, S2 e S3)/species, where CV = variable costs; CF = overhead costs e CT = total costs.

Componentes	S1	S2		S3	
	Algae	Algae	Oyster	Algae	Mussel
Average costs					
CV (US$/kg)	0.70	0.78	1.62	0.60	0.60
CF(US$/kg)	0.47	0.41	0.38	0.41	0.35
CT (US$/kg)	1.18	1.19	2.00	1.01	0.96
Total cost					
Production (kg)	24,192	13,608	41,667	13,608	40,000
Cost (US$/kg)	1.50	1.50	3.11	1.50	1.40
Gross revenue/species (US$)	36,288.00	20,412.00	129,584.37	20,412.00	56,000.00

Gross revenue/system (US$)	36,288.00	149,996		76,412	
CT (CV + CF)/species (US$)	28,546.56	16,193.52	83,334.00	13,744.08	38,400.00
CT (CV + CF)/systems (US$)	28,546.56	99,527.52		52,144.08	
Profit					
Net profit/species (US$)	7,741.44	4,218.48	46,250.37	6,667.92	17,600.00
Net profit/systems (US$)		50,468.85		24,267.92	
Percentage of net profit on revenue					
Net profit	21.33%	20.67%	35.69%	32.67%	31.43%
Production cost species	78.67%	79.33%	64.31%	67.33%	68.57%
Production cost systems		71.82%		67.95%	

Besides, it prevents overload and lesions caused by repetitive stress usually occurring in mariculture activities (DUTRA et al., 2011).

The net profit in S2 (US$ 50,468.85/ha/yr) (Table 7) is 6 times higher than in S1 and 2 times higher than in S3, producing a yearly family income (1.57 ha per marine farmer) of US$ 79,236.09 or monthly income of US$ 6,603.00. The lowest net income is verifyied in S1, where the yearly family income is US$ 12,154.06 monthly US$ 1,012.84. Any of the three systems (S1, S2 and S3) pays at least 4 times the established brazilian minimum salary of monthly US$ 232.45 or yearly US$ 2,789. In the Phillipines, the monthly family income obtained with algae cultivation varies from US$ 632.00 to US$ 1,895.00 (FAO, 2013; HURTADO et al., 2013). The monthly family income in Indonesia is around US$ 416.00, well over the country's per capita income (US$ 298.33 per month) (ZAMRONI; YAMAO, 2011; FAO, 2013; HOLTZ, 2015). In Zanzibar (Africa), the daily average income obtained with seaweed cultivation is US$ 1.00 per day per worker, which is considered under the poverty line (FROCKLIN et al., 2012). The average yearly income in Chile provided by *Gracilaria* cultivation was US$ 29,640/ha (MARTINEZ et al., 1990), which is 74% higher than the income obtained in S1 system, but 70% lower than S2 system.

Comparing the production costs of the envolved species, the oyster presents the higher cost (US$ 2.00/kg), followed by the seaweed (which varies from US$ 1.01 kg to US$ 1.18 kg/dry seaweed) and mussel (US$ 0.96/kg). The dry seaweed production cost in Tanzania was US$ 0.06/kg/yr, in Mexico US$ 0.66/kg/yr and in Phillipines US$ 0.70/kg/yr (VALDERRAMA et al., 2015). Generally, the S1 system reveals the highest production cost, percentually 78,67%, followed by S2 (71,82%) and S3 (67,95%) (Table 8). The net profit provided by seaweed in S1, S2 and S3 is, respectively, US$ 0.31/kg/yr, US$ 0.32/kg/yr and US$ 0.49/kg/yr of dry seaweed. This profit was, for Indonesia, US$ 0.58/kg/yr, for

Philippines US$ 0.39/kg/yr, for Mexico 0.35/kg/yr, for Tanzania US$ 0.20/kg/yr, for Solomon Islands US$ 0.11/kg/yr and for India US$ 0.06/kg/yr (VALDERRAMA et al., 2015).

The three production systems of *K. alvarezii* are economically and financially viable as per analysis of the Table 8 indexes. Bicultivation system with *Crassostrea gigas* oyster (S2) shows the most attractive indexes as compared with the two other systems.

Table 8: Economic and financial viability indicators of macroalgae production *K. alvarezii* in monoculture systems (S1), biculture with oyster *Crassostrea gigas* (S2) and biculture with mussel *Perna perna* (S3). The November 2014 values (Financial data from production costs, where IRR = internal rate of return, NPV = net present value for the three culture systems.

Components	IRR(%)	NPV(US$)	PayBack (months)
S1	23.21	73,090.22	59.07
S2	59.33	569,468.01	23.22
S3	38.26	279,896.63	36.52

For the three macroalgae production systems, the NPV is greater than zero and the IRR greater than MAT (minimum attractivity index) which was established to be 11,25%, thus proving the economic and financial viability of each system considering a time span of 9 years (108 months). The payback occurs between 23 to 59 months (Table 8).

The monoculture system (S1) produced a IRR of 23.21%, the lowest among the studied systems. The NPV resulted more than zero, or about US$ 73,090.22 in estimated monetary value, and the payback time estimated in 59.07 months, the longest payback time among the studied systems. This system requires the longest return time of the applied investment and showed a IRR of 23.21%, which is lower between the systems. Even so, that the monocultivation system (S1) still rewards two times more than MAT of the invested capital in the system, becoming a very atractive system.

The biculture system with *Crassotrea gigas* (S2) revealed the most attractive economical and financial indexes, followed by S3 system. The IRR estimated for S2 system was 59.33%, while the NPV showed an additional result of US$ 569,468.01, 2.03 to 7.79 times greater than the other two systems. Moreover, the invested capital return time (cashed payback) of 23.22 months is the shortest among the studied systems.

The S2 system produced the best social benefit in the form of generated jobs (1,679 jobs), followed by S3 (934 jobs) and S1 (280 jobs), regarding direct employments in the implantation and production stages (Table 9).

Table 9: Generating employment, with labor fixed and contracted to Santa Catarina's aquaculture parks, in the three culture systems during the stages of implementation and production, beyond the sum of the two steps.

Implantation + Production	S1	S2	S3
Man day/ha (Implantation + Production)	74	522	247
Working days (2014)		256	
Mans/ha	0.29	2.04	0.96
Aquaculture park (ha)		968	
Implantation + Production	**280**	**1,974**	**934**
Implantation	**121**	**295**	**212**
Production	**159**	**1,679**	**722**

The mechanized production proposal of the seaweed can reduce about 67% of the manpower hiring in comparison with the manual cultivation in floating rafts as shown in Valderama (2015). For Santa Catarina's marine farmers, the labor is the main hindrance in their way to expand and diversify their cultivations. The mechanized production systems may be a solution to this problem. The proposed systems require 2.3 people to produce 24.192 t $ha^{-1}year^{-1}$ dry seaweed, or 950 people to produce 10,000 t/ha/yr dry seaweed. In Tanzania, 2,800 people are necessary to produce 10,000 t/ha/yr (MSUYA; PORTTER, 2014; VALDERRAMA et al., 2015). New cultivation technologies are being developed so as to increase the production and the productivity of the seaweed marine farms. In India, a new methodology was developed by engineers which is considered the next acquaculture borderline to make possible the seaweed cultivation practically anywhere in the ocean (Holtz, 2015).

5. Conclusions

The culture of sea algae worldwide has been pointed as an adequate activity to family aquaculture, with social and economic benefits, and increase in employment rates in traditional communities.

The economic and financial assessment of integrated sea cultures featuring mollusks and algae is relevant due to its originality in Brazil. Current study ranks first and good results may be a great help to producers in their decision to adopt the proposed technology. Culture integration revealed additional profits, ranging between 8 and 27%, besides profit from the mollusks.

Culture S2 system with algae and oysters provided the highest profit rate. Investment is higher in this system, coupled to the best profitability, plus more employment rates when compared with other systems.

Current study demonstrated that the Aquaculture park of Santa Catarina is underused: the monoculture of mollusks is not attractive for producers; the diversification with macroalgae may triggerbetter use of sea farms; macroalgae production in the state, within an integrated system, may amount to 13,192.28t/yr, significantly equivalent to 16% of the world first producers (Indonesia) and 21% of the second (the Philippines).

For these reasons, the Aquaculture Park of Santa Catarina presents technical, environmental, economic, financial and social conditions for the integration of the mollusks and seaweed *K.alvarezii* cultivations, enabling the development of new species, reducing the financial risks and improving the income of the family involved in the activity.

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