The potential for carbon dioxide sequestration in the biomass of the seaweed *Kappaphycus alvarezii* in the marine farms of Santa Catarina

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Abstract – The Federal Government of Brazil has developed the proposal for Project of Law No. 2148/15 to regulate the national carbon market, promoting the generation of national methodologies for quantifying greenhouse gases, adapted and adjusted to the species involved, the climate and the several Brazilian biomes. Seaweed occupy a prominent position among the species capable of absorbing CO_2. For *Kappaphycus alvarezii*, the average captured C content is 1.7% of its live weight. Following the methodology proposed by the Intergovernmental Panel on Climate Change protocol, the volume of C and CO_2 sequestered by *K. alvarezii* in Santa Catarina was calculated based on three different scenarios. The CO_2 sequestration potential of marine farms in Santa Catarina, calculated from the average productivity of the state's first two harvests (2021/2022 and 2022/2023), was 2,292.71t harvest^{-1} of CO_2 and 624.72t harvest^{-1} of C. These results illustrate the importance of Santa Catarina in accessing this promising carbon credit market, boosting the profit of Santa Catarina's marine farms.

Index terms: *Kappaphycus alvarezii*; Algiculture; Carbon trading.

Potencial de sequestro do dióxido de carbono na biomassa de macroalga *Kappaphycus alvarezii* nas fazendas marinhas de Santa Catarina

Resumo – O Governo Federal elaborou a proposta do Projeto de Lei Nº 2148/15, para regulamentar o mercado nacional de carbono e, com isso, promover a geração de metodologias nacionais para quantificação dos gases do efeito estufa, adaptadas e ajustadas às espécies envolvidas, ao clima e aos diversos biomas brasileiros. Dentre as espécies capazes de absorver CO_2, as algas assumem posição de destaque. Para a *Kappaphycus alvarezii*, o teor médio de C capturado é de 1,7% de seu peso vivo. Seguindo a metodologia proposta pelo protocolo *Intergovernmental Panel on Climate Change*, foi calculado o volume de C e CO_2, sequestrado pela *K. alvarezii* em Santa Catarina, com base em 3 diferentes cenários. O potencial das fazendas marinhas catarinenses de sequestro de CO_2, calculado a partir da média de produtividade das duas primeiras safras do Estado (2021/2022 e 2022/2023), foi de 2.292,71t safra^{-1} de CO_2 e de 624,72t safra^{-1} de C. Esses resultados ilustram a importância de Santa Catarina em acessar esse promissor mercado de créditos de carbono, aumentando o lucro das fazendas marinhas catarinenses.

Termos para indexação: *Kappaphycus alvarezii*; Algicultura; Comércio de carbono.

Introduction

The carbon credits (CC) market has become popular worldwide over the last decade and is growing rapidly, largely driven by greenhouse gases (GHG), which also impact global warming, promoting climate changes that are affecting the ecological balance that we know. This environmental and financial cost led to the creation of a mitigation market, the "carbon credits market", which assigned a value to each ton of carbon that is no longer released into the atmosphere, rewarding those who help to remove carbon dioxide (CO_2) from the environment, generating CC that can be sold to companies and countries that have not reached their CO_2 reduction targets.

The carbon (C) market emerged from the Kyoto Protocol in 2005, which laid the foundations for global C trade and, since then, analysts believe that it could become a new commodity. Although C emissions in Brazil are low when compared to other countries, the Brazilian scientific and political community has been discussing and learning about this new market, proposing public policies for its development, thus contributing to the reduction of CO_2. Some experts believe that Brazil has billion-dollar potential to become a CC exporter, being able to generate approximately US$100 billion in revenue by 2030, with emphasis on opportunities in the agricultural and energy sectors (CNA, 2023).

Brazilian legislation that regulates this market is still fragile and incomplete, but discussions and improvements are underway. In 2022, the Government issued a decree that intended to regulate the CC market in Brazil to export CC to countries and companies that need to offset their emissions and comply with their commitments to reduce C emissions (Gomes, 2022). Based on this decree, a proposal for a bill to regulate the C market was drawn up and is under approval in the Federal Chamber, which in turn already has seven bills on the subject (PL 2148/15) to be voted on an urgent basis. The objective is to approve a final text and present it at the UN Conference on "Climate Change", scheduled to take place in Belém/PA, in 2025, COP-30 (Oliveira, 2023). This legislative framework intends to create the "Brazilian Emissions Trading System", in which companies would be regulated and receive emission quotas to be fulfilled. Those that emit less would have quotas related to avoided emissions and those that emit more would have to compensate within the regulated market or as part of the voluntary market.

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In addition to the regulatory system, another deficiency in Brazil is the establishment of methodologies for evaluating the amount of carbon captured to be transformed into CC. Although there are different valid, accredited, recognized and used methodologies worldwide for quantifying GHGs, they need to be adapted and adjusted to the biological characteristics of the species involved and the climatic characteristics of the different biomes; therefore, their "adaptation" is not as simple as it seems. Information and studies to enable the audit and certification procedures of the enterprises that join this process are lacking in Brazil. In this sense, the forestry sector is a little more developed, but agriculture has some additional challenges, as it is much more dynamic, facing great influence from climate, soil and management that affect carbon sequestration (CNA, 2023). If there are challenges for forests and agriculture, those of mariculture or marine crops are even greater, as CO_2 emissions originating from the activity are still little studied in worldwide, despite the importance of the oceans for life, as they cover more than 70% of the planet's surface and are responsible 55% of the Earth's oxygen production, through seaweed. This value of the oceans to the planet should be proportional to the volume of studies dedicated to it, but it is not!

Carbon dioxide sequestration

Data from the IPCC (Intergovernmental Panel on Climate Change) reveal that the oceans can absorb up to 2 billion tons of CO_2 per year, though conflicts regarding estimates of this absorption exist (Windowati *et al.*, 2012). One of the reasons is the lack of sufficient annual production data for primary producers, including marine plants, and studies are needed to improve our understanding of the amount of carbon absorption by marine plants (Murakoa, 2004). In the last decade, studies have intensified and seaweed production has grown in volume and importance for C capture. The percentage of C capture varies between and within algal species (Sodak *et al.*, 2017). For *K. alvarezii*, the C content is 20.73 ± 1.73% of its dry weight (Windowati*et al.*, 2012; Viana, 2021). If we consider fresh seaweed, the C content is 1.6 to 1.8% of its weight (Windowati*et al.*, 2012; Viana, 2021). According to Sandok *et al.* (2017), the productivity of *K. alvarezii* can reach 150t há$^{-1}$ year^{-1}, with a ratio between wet weight and dry weight of 10:1, that is, 10kg of live algae is equivalent to 1kg of dry algae. Considering that the wet weight has an average carbon percentage of 1.7% and considering a productivity of 150t há$^{-1}$ year^{-1}, we have: 150t ha^{-1} year^{-1}. Following the IPCC protocol for tracking changes in C stocks and to facilitate comparison between most other assessments, we express ecosystem C in terms of potential CO_2 emissions, obtained by multiplying C stocks by the factor 3.67, the molecular weight ratio of CO_2 to C (Pendetlon *et al.*, 2012; Sodak *et al.*, 2017; Viana, 2021). Thus, 3.67 multiplied by 2.55t of fixed C ha^{-1} year^{-1}, leads to a CO_2 absorption of 9.36t ha^{-1} year^{-1} by *K. alvarezii* (Sodak *et al.*, 2017; Viana, 2021).

Following the methodology presented above, proposed by Sodak *et al.* (2017) and used by Viana (2021), the volume of C and CO_2, sequestered by the macroalga *K. alvarezii*, was calculated in the 2021/2022 and 2022/2023 harvests, in 22 marine farms in Santa Catarina and the total potential of installed cultivation in the State, which totals 720 marine farms and totals 1,178.71ha, offered in tenders held in 2012 and 2013 by the Ministry of Fisheries and Aquaculture (Santos, 2014). Table 1 presents 3 projections of CO_2 sequestration and C production, based on 3 different productivity scenarios (S1, S2 and S3). S1 refers to the average productivity of the first two algae harvests in the State, which reached 31.32t há$^{-1}$ year^{-1}, with only 2.2 cultivation cycles, considered low, but justifiable, given the inexperience of producers and the atypical climatic conditions, with record rainfall volumes that devastated the state in 2022 and 2023. In 2022, in the months of November and December, rain fell for 120 hours, 613mm in Santo Amaro, 379mm in Florianópolis, 376mm in Palhoça, in addition to similar volumes in neighboring municipalities, resulting in an abrupt drop in salinity in the Southern Bay, the main algae producing area, causing mortalities that ranged from 80 to 90%, compromising the productivity of the first two state harvests (Santos *et al.*, 2023). The S2 refers to the productivity prospected in the studies by Santos *et al.* (2018) for SC of 21.50t ha^{-1} cycle^{-1}, totaling 64.51t ha^{-1} year^{-1}, but with only 3 annual crop cycles. However, from 2018 to 2023, the expected projections for the coast of Santa Catarina increased from 3 to 4 annual crop cycles and with this, the State could reach 86.01 t ha^{-1} year^{-1} (21.50t ha^{-1} cycle^{-1} x 4 cultivation cycles). But in addition to the increase in cultivation cycles, the 2018 productivity data were obtained from small research units and needed to be compared with data from large-scale cultivation. For this reason, S3 relates to two producers who stood out with the highest productivity from 2020, with the beginning of commercial cultivation, when Epagri carried out harvest monitoring and identified productivity that varied from 120 to 135t ha^{-1} year^{-1}, with 32t ha^{-1} cycle^{-1} or 70.4t ha^{-1} year^{-1} on average, with 2.2 cultivation cycles, but extrapolated to 4 possible cultivation cycles, reaching 128t ha^{-1} year^{-1} (Table 1).

Observing the data in Table 1, it can be seen that in the 2022/2023 harvest, the state average for CO_2 sequestration by *K. alvarezii* was 18.74t ha^{-1} and C was 0.53t ha^{-1}, with only 2.2 cultivation cycles (S1). In the coming years, these values should increase to 38.59t ha^{-1} of CO_2 and 1.10t ha^{-1} of C, considering 3 cultivation cycles (S2). However, it is important to highlight that these values can be even higher with the increase in producers' experience, reaching 76.58t ha^{-1} of CO_2 and 2.18t ha^{-1} of C, as occurred with the two largest algae producers in Santa Catarina (S3).

With the data presented in Table 1, it was possible to calculate the installed capacity for C and CO_2 sequestration, by marine farms in Santa Catarina, using the current productivity of the 2022/2023 harvest (31.32t ha^{-1} ha^{-1} year^{-1}), resulting in 624.72t year^{-1} of C and 2,292.71t year^{-1}. However, in the near future, considering 4 cultivation cycles and 128t ha^{-1} year^{-1} as the average productivity of S3, the projection is that the C sequestration potential will reach 2,569.59t year^{-1}and CO_2, 9,430.39 59t year^{-1} (Table 2).

Final considerations

This article aimed only to address the ability of *K. alvarezii* to absorb CO_2. The fate of the captured CO_2 was not the subject of this work. The results were obtained through a methodology proposed by foreign authors (Sodak *et al.*, 2017), but it is imperative that Brazil develop its own measurement methodologies, with scientific credibility, accreditation, subject to certification and audit, thus acquiring independence from

external certification agencies. It is in search of this knowledge that the State Government, through Epagri, and the Santa Catarina shellfish farmers intend to act, so that the production of *K. alvarezii* can be monetized, through environmental assets that the Brazilian C trade can provide to algae producers.

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Table 1. Potential for C and CO2 production by the macroalga *K. alvarezii*, based on production and productivity from the 2022/2023 harvest and research results, operating under three productivity scenarios, S1, S2, and S3 (see text)

Tabela 1. Potencial de produção de C e de CO_2, pela macroalga K. alvarezii, a partir da produção e das produtividades da safra 2022/2023 e de resultados de pesquisa, operando em 3 cenários de produtividade, S1, S2 e S3 (vide texto)

Safra	Produção (t)	Área (ha)	Ciclos de cultivo (nº)	Produtividade média (t ha^{-1} $ciclo^{-1}$)	Produtividade média (t ha^{-1} ano^{-1})	C alga	C (t/ha/ano)	C Total (t ano^{-1})	Fator de conversão de C em CO_2	CO_2 (t/ha/ano)	CO_2 Total (t/ano)
S1 (2022/2023)	300,35	9,59	2,2	14,24	31,32	1,7%	0,53	5,11	3,67	18,74	179,71
S2 (Projetada)	300,35	9,59	3	21,50	64,50	1,7%	1,10	10,52	3,67	38,59	370,09
S3 (Projetada)	300,35	9,59	4	32,00	128,00	1,7%	2,18	20,87	3,67	76,58	734,45

Table values were rounded to two places after the decimal point.

Valores da tabela foram arredondados para duas casas após a vírgula.

Table 2. Potential for C and CO2 sequestration by the macroalga *K. alvarezii* in 100% of marine farms in Santa Catarina, for the current and future harvests, considering the productivity by cultivation cycle of the current 2022/2023 harvest and the expected productivity by cultivation cycle

Tabela 2. Potencial do sequestro de C e CO_2, pela macroalga K. alvarezii, em 100% das fazendas marinhas de Santa Catarina, na safra atual e futura, considerando a produtividade por ciclo de cultivo da atual safra 2022/2023 e a produtividade esperada por ciclo de cultivo

Produtividade (t ha^{-1})	Parque Aquícola (ha)	C Fixado (t ha^{-1} ano^{-1})	C Total fixado/safra (t ano^{-1})	Fator de conversão de C em CO_2	CO_2 (t ha^{-1} ano^{-1})	CO_2 Total fixado/safra (t ano^{-1})
Atual	1.178,71	0,53	624,72	3,67	2.292,71	2.702.438,81
Futura	1.178,71	2,18	2.569,59	3,67	9.430,39	11.115.691,73