Carbon capture in Latin American algal meadows: a case study on South American pacific coast

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Abstract

Algal meadows can significantly contribute to carbon (C) capture; nevertheless, few studies on South American Pacific coast reserves are available. Evaluation of these stocks allows proposing better measures for the sustainable use of these habitats and maintaining their ecosystem services. This study aimed to estimate biomass distribution and quantify the C captured in algal meadows of *Chondracanthus chamissoi* on the Laguna Grande coastal lagoon (Ica-Peru). To calculate the biomass, the area occupied by each patch of algae in each sampling zone was delimited and transects perpendicular to the coast were used in randomly located plots. To calculate the biomass, randomly located plots of algae transecting perpendicular to the coast were located in each sampling zone and delimited. In the laboratory, the dry biomass and C content were measured (the latter using an elemental analyzer). Monthly variation in the distribution and area was identified. September 2021 presented the highest total biomass (50416.4 kg; 50.4 t) and C captured (13 t C) while from February to June no algal biomass was found. Significant differences were found in the biomass and C capture in the sampling zones, the months of C capture, and the interaction between these two variables. C capture decreases with warm months and more intensive algae extraction. Our results provide valuable information on the distribution of biomass and C captured over time in the study area, which will help create a more sustainable extraction process.

Introduction

The increase of greenhouse effect gases as a result of human activities represents one of the most critical problems of this century (Dai et al. 2017). The Intergovernmental Panel on Climate Change has proposed nature-based solutions with a critical approach for its mitigation and reduction (Cohen-Shacham et al. 2016). These solutions include care, restoration, and sustainable use of environments that serve as carbon storage and capture (Pendleton et al. 2012). Carbon capture implies the retention of carbon in biomass (inside the body of organisms) (Barnes et al. 2021) for a short time as part of an organism cycle (Duarte et al. 2005) as well as the transfer of atmospheric carbon dioxide to other long-lived reserves, such as oceanic, pedological, biotic and geological sediments (Lal 2008), which can remain for thousands of years (Nellemann et al. 2009; Vierros 2017). Vegetated marine-coastal ecosystems, including mangroves, kelp beds, seagrasses, and salt marshes, store and sequester large amounts of carbon, called “blue carbon” (Barbier et al. 2011).

Initially, algal meadows were not considered a possible blue carbon contributor (Duarte et al. 2005) due to their limited long-term potential for carbon sequestering (Smale et al. 2018). However, recent studies have demonstrated that thanks to the source-sink mechanism (transport of a large amount of biomass of algae from euphotic coastal waters to the seabed), macroalgae can contribute significantly to the vertical flux of organic carbon and its sequestration in ocean sediment (Oreska et al. 2918; Hidayah et al. 2019). Occasional deposits of *Macrocystis* sp. and *Sargassum* sp. on the seabed off the east and west coasts of the United States and in the Caribbean have been described (Harrold et al. 1998; Kokubu et al. 2019).

Currently, it has been proposed to consider all pathways of the carbon cycle as blue carbon, based on the "Odum outwelling" hypothesis, which suggests that lateral flows or horizontal exports of carbon sustain a large part of biological productivity (Odum, 1968). Algae meadows can also be considered blue carbon contributors by having exceptionally high rates of primary production per unit area and transporting dissolved and particulate organic carbon (Santos et al. 2021).

Algal habitats are the most extensive and productive coastal habitats in the ocean, covering about 6.06–7.22 million km^2, and support a primary global net production of around 1.32 Pg C yr^{-1} (Duarte et al. 2022). Carbon capture studies have been carried out on *Macrocystis pyrifera*, obtaining a net annual productivity of 0.0013 t C m^{-2} (Wheeler and Druehl 1968). Furthermore, the influence of physical parameters, such as temperature, on carbon capture has been described; for example, *Laminaria hyperborea* forests in warm regions of the Northeast Atlantic capture less carbon (3.09 t C ha^{-1}) than in cold areas (9.72 t C ha^{-1}) (Pessarrodona et al. 2018).

Despite this, studies are limited and most information regarding carbon stock is focused on seagrasses and mangroves (Donato et al. 2011; Ricart et al. 2020), showing an information gap that must be addressed.

On the South American Pacific, carbon capture studies have been carried out on populations of *Lessonia nigrescens* and *Lessonia trabeculata* in Chile (during spring was estimated at 11.46 g C m^{-2} d^{-1} and 2.46 g C m^{-2} d^{-1} respectively; in autumn to 0.66 g C m^{-2} d^{-1} and C m^{-2}, respectively) (Tala and Edding, 2007). In Peru, despite identifying the need for adequate mapping and effective quantification of the level of carbon sequestered by algal meadows (McKinley et al. 2019), few studies are available. Regarding scientific articles, there is only the research by Aller-Rojas *et al*. (2020) in *Lessonia trabeculata* forests in San Juan de Marcona, in which the carbon capture potential of *L. trabeculata* is highlighted by presenting a capture of 4.31 ± 1.56 t C ha^{-1}. This study suggests that research must be continued on the carbon dynamics of marine algal ecosystems in the Humboldt Ecoregion.

Chondracanthus chamissoi is a benthic marine red macroalga that is located between Paita, Peru (5°S) to Ancud, Chile (42°S) (Wang et al. 2012), with a distribution from the lower intertidal zone, up to 15 m deep (Bulboa and Macchiavello 2006). This species is considered one of the most important due to its potential use to obtain carrageenan (Bulboa et al. 2005). In the Ica region, mainly in shallow areas of the coast, its extraction is carried out by artisanal fishermen as an economic sustenance activity, with biomasses of 180 t, 30.1 t, and 2.1 t having been reported for the Atenas, Puerto Nuevo, and Lobería beaches, respectively (autumn of 2010) and registered reductions in the last two prairies compared to 2007 due to the intensification of extractive activity (Flores et al. 2015). Intensified and disorderly extraction is the potential cause of resource decline, and this may be aggravated by the effects of climate change and phenomena such as "El Niño" and "La Niña" (Vivanco et al. 2014). The reduction of algal biomass affects carbon capture in ecosystems (Macreadie et al. 2013) and, thus, the carbon cycle; For this reason, it is essential to ensure sustainable use of the resource that allows maintaining the ecosystem services that algal meadows provide (McKinley et al. 2019).

In this context, the objective of this research was to describe the distribution of algal biomass in algal meadows of *C. chamissoi* between August 2021 and September 2022 and estimate its biomass per unit area and carbon capture in the Laguna Grande coastal lagoon (Ica-Peru), which is one of the areas of high interest for being the main extraction center of this species.

Materials and methods

Study area

The study was conducted in Ica-Peru in the province of Pisco, located south of Lima (Fig. 1). The research focused on the Laguna Grande coastal lagoon, which has a semi-enclosed formation that covers 299.29 ha (Quispe et al. 2010). Four sampling zones were chosen for the main extraction points of *C. chamissoi*: Bocana, La Isla, Bajada de León, and Criadero.

This area presents a textured bottom of the coarse sand type, with rock fragments, shell remains, and fan shells (Velazco and Solís 2000), which allow the fixation of *C. chamissoi*. Criadero, Bocana, and La Isla are shallow areas with depths between 1 and 3 m, while Bajada de León is an area with a depth between 4 and 8 meters (Quispe et al. 2010).

The study was conducted between August 2021 and September 2022, performing monthly sampling (except for July and August 2022, when logistical conditions did not allow sampling).

The distribution and area of each sampling zone

Each sampling zone was delimited according to the presence of *C. chamissoi* and a motorboat was used to delimit every contour. Furthermore, a freediver validated the presence or absence, and the limits were georeferenced with the help of a GPS (Garmin model GPSMAP 64sx) receiver. Finally, considering these limits, polygons were built, and then the area of each sampling zone was calculated using QGIS Desktop 3.16.5 software (Sherman 2022).

Biomass in each sampling zone

To determine the biomass in each sampling zone, a transect was carried out parallel to the coast that crossed the *C. chamissoi* population through the central part and from end to end. The length of each transect was determined with GPS and was conditioned to biomass variations (increase or decrease over time). Algal biomass was recorded in PVC quadrats of 25 cm x 25 cm, randomly placed along each transect by a scuba diver. Since the area of each sampling zone differed, between 12 and 32 points were made for each transect, verifying that it was representative of the population using a performance curve (Elzinga et al. 1998). In each quadrant, the algae were extracted from the substrate and excess water was removed with blotting paper. Subsequently, the biomass was weighed on an electronic balance (FERRAWYY brand model BAG030-YJ; 5 g precision). This procedure was carried out in each month evaluated. Finally, each month the values of the sampling zones were added to determine the biomass of the total monthly algal population.

Percentage of dry biomass and percentage of carbon

To calculate the dry weight percentage, three samples of *C. chamissoi* were taken to the Algaex S.A. laboratories. and weighed (wet weight). They were subsequently dried in a dehydrator at 38°C for 48 hours. A moisture analyzer (MX-50, 0.005 g precision) was used to verify that the moisture percentage was null. The difference between the wet and dry weights indicated the percentage of dry biomass (DB), corresponding to the average results obtained from the three samples.

Three additional samples were collected and processed in the ELTRA CS-2000 elemental analyzer in the Soldexa S.A. laboratories to know the percentage of carbon in the biomass. The average result in the three samples was used as the carbon percentage of the biomass.

Calculation of carbon capture in each sampling zone

To calculate the average carbon capture in each sampling zone (C), the average biomass of the quadrats of each population (B) was multiplied by the percentage of dry biomass (%DB) and by the percentage of carbon in the biomass (%C), following formula 1:

$C = B \times \% DB \times \%C \ldots (1)$

This value was multiplied by the area of each sampling zone, showing the total carbon capture of each sampling zone in each month evaluated. Finally, the values obtained for each sampling zone were added to determine the total carbon capture of each month in the study area.

Statistical analysis

Descriptive statistical analysis (means and standard deviations) was performed for the biomass values of the plots in each sampling zone. Graphs and tables were made with these values. All this was done in Excel software (Microsoft ®, licensed). To compare the carbon capture of each sampling zone over time, a PERMANOVA test was carried out. This test allows evaluating the dependent variable (carbon capture) based on two or more independent variables (in this case, the sampling area and the sampling month), verifying the relationship between the dependent variable and the interaction between the independent variables. This test was chosen since the dependent variable did not meet the normal distribution ($p < 0.05$ for the Shapiro-Wilk test). This analysis was performed in the PAST 3.17 software (Hammer et al. 2001).

Results

Distribution and area of each sampling zone

The locations of the sampling areas were the same in August and September 2021 (Fig. 2a). In October 2021 (compared to September), an increase in area was evidenced in 64% and 29% of the sampling areas of Criadero and the Island respectively, while the area in Bocana decreased by 57% and the area in Bajada de León was maintained (Fig. 2b and Supplementary Material S1). On the other hand, in November 2021 (compared to October), the sampling areas of Criadero and La Isla, decreased by 93% and 53%, respectively, while Bocana increased by 27% and the area in Bajada de León was maintained (Fig. 2c and Supplementary Material S1). In the December 2021 sampling, the Criadero sampling zone increased in area by 236% and La Isla decreased in area by 98%, while the Bocana algal population disappeared (Fig. 2d and Supplementary Material S1). In the sampling of January 2022, the distribution of the sampling areas of the first sample was used (the low density did not allow clearing the established limits). In that month, there was no record of algal biomass in Criadero (Fig. 2d and Supplementary Material S1). There was no record of algal biomass in February, March, April, May, June, or July 2022. Finally, in the September 2022 sampling, only the La Isla, Criadero, and Bocana patches were identified, with the distribution and areas being different from those found in September 2021 (Fig. 2e and Supplementary Material S1).

Biomass in each sampling zone

The average wet biomass in the Bocana algal population was higher in November 2021 with 3.99 ± 2.59 kg m^{-2} with an estimated this biomass of 14389.40 kg. Between December 2021 and June 2022, there was no algal recorded. Regarding the algal population of La Isla, the highest wet biomass was also recorded in November 2021 with 4.85 ± 2.96 kg m^{-2} and an estimated total biomass of 57258.5 kg, with no record of algal biomass between February and June 2022. Regarding Bajada de León, in September 2021, the highest value of wet biomass was obtained with 15.52 ± 7.91 kg m^{-2} and an estimated total biomass of 381431.6 kg. This value was the highest achieved compared to the remaining sampling areas. Finally, similar to Bajada de León, Criadero registered the highest wet biomass in September 2022 with 6.20 ± 3.65 kg m^{-2}, and an estimated total biomass of 53109.6 kg. January was the month with the lowest registered wet biomass in all the sampling areas with 0 kg m^{-2}, 0.17 ± 0.89, 0.12 ± 0.17 and 0.16 ± 0.1 for Bocana, La Isla, Bajada de León, and Criadero, respectively (Fig. 3).

Carbon capture in the sampling zone and statistical analysis

The general average of % DB was 10 ± 0.01 and the % C was 25.83 ± 0.57. The highest value of DB was found in September 2021 (in an area of 52030.4 m^2) with a value of 50.42 t and a carbon capture of 13 t C with an equivalence of 7.46 t C ha^{-1} and the lowest non-zero value in January 2022 (in an area of 52030.4 m^2) with a value of 6.6 t and a carbon capture of 0.17 t C with an equivalence of 0.12 t C ha^{-1} (Fig. 4, Supplementary Material S1). In addition, the results indicate a peculiarity, where in September 2022, biomass as high as September 2021 is not reached. In addition, it was of note that the biomass obtained in September 2022 was not as high as that achieved in September 2021.

On the other hand, the most significant extraction of *C. chamissoi* occurred between July and October (cold months) while between January and May (warm months), the activities ceased.

The extraction cycle is directly related to the maximum algal biomass reached by *C. chamissoi* during winter and spring (Fig. 4). Furthermore, the maximum biomass is directly proportional to carbon capture (Fig. 4).

There were significant differences in carbon capture between the sampling areas, months, and the interaction between these last two variables (PERMANOVA, area: $F(3) = 6.28$, $p = 0.0003$; month: $F(6) = 55.24$, $p = 0.0001$; interaction: $F(3, 6) = 8.98$, $p = 0.0001$) on analyzing the carbon capture of the four sample areas studied (Bocana, La Isla, Bajada de León, and Criadero) and the months studied.

Discussion

Distribution and area of each sampling zone

The differences registered in the distribution and area of the algal population during the sampling months (Fig. 3) are related to bathymetric factors and extraction of the resource. Criadero, Bocana, and La Isla are shallow areas, while Bajada de León is a deeper area (Quispe et al. 2010). The characteristics of the latter area make it less accessible; therefore, compared to the other areas, its extraction is less intensive and the area is maintained over time. In contrast, Bocana, which is a few meters from the shore, has more significant extractive pressure, and therefore, its area decreases monthly from August 2022 until it disappears. La Isla and Criadero are at a midpoint regarding access to extraction, which makes them moderate regions chosen for these purposes for extraction purposes.

Percentage of dry biomass and percentage of carbon

No similar studies regarding the % DB and % C of *C. chamissoi* are available. However, the results of the present study are similar to those registered in the macroalga *L. trabeculata* in which the % DB is 12.99 ± 0.65 and the % C is 28.84 ± 4.59 (Aller-Rojas et al. 2020) and in *L. nigrescens* in wich the %C = 27.23 ± 1.07 in spring and % C = 23.44 ± 1,92 to 22.32% in Autumn).

In relation to other species of vegetated marine-coastal ecosystems, the %C values reported for *C. chamissoi* are lower than those reported for the seagrass *Thalassia testudinum* with which %C is equal to 35% (Acosta-Chaparro et al. 2022) or for wetland species with a %C of 33.77% ± 7.05 having been recorded in succulent plants, 39.25% in floating aquatic plants and 48.97% ± 9.32 in amphibian herbs (Aldave and Aponte 2019).

These results could be related to the fact that most woody and slow-growing plants require a greater investment of C at the cellular level to synthesize lignin (a polymer that allows the formation of support structures such as thallus) (Nielsen et al. 1996; Ma et al. 2018). In contrast, species with a high growth rate and less complex structures lead to less demand for C (Johnson et al. 2007), as is the case of *C. chamissoi.*

Biomass of each sampling area and carbon capture

September was found to be the month with the highest total algal biomass of *C. chamissoi* (Fig. 4). These results differ from those found in La Libertad, which reported that November presents the highest average biomass with an average value of 650.69 t compared to August-September with 277.77 t (Uribe et al. 2018). However, considering the biomass per area unit, both studies found that November and September are the months with the highest biomass in the study areas.

Similar studies have been carried out in other species of algae *L. nigrescens* and *L. trabeculate* in Chile, where the biomass and carbon contents showed significant differences between the two sampling periods, with higher values during spring (Tala and Edding, 2007).

The extraction pressure and its relationship with the bathymetry seem to be one of the main factors determining the differences between the sampling areas (Quispe et al. 2010; Flores et al. 2015). This also affects the carbon capture in the study area; carbon is harvested with it when the algae are harvested. Null carbon capture during the warm months is because the maximum biomass extraction occurs in winter-spring, a pattern also observed in *C. chamissoi* meadows in La Libertad (Uribe et al. 2018). By extracting the alga entirely from the area, there is no algal biomass in the summer months until its subsequent recruitment and germination in winter-spring (Pariona and Gil-Kodaka 2011).

On the other hand, even though Bajada de León presents lower extraction pressure and is the deepest zone, in some cases, the average values of biomass per unit area are lower than those of the rest of the sampling zones. This could be because as it is a deeper zone, it presents less availability of light, affecting the algae's proliferation by reducing its photosynthetic activity (Yu et al. 2013). These results coincide with similar studies that described a decrease in biomass at greater depth, demonstrating the growth preference for *C. chamissoi* at depths between 1 and 4 meters (Bulboa et al. 2005; Macchiavello et al. 2018) and at high levels of irradiance (Bulboa and Macchiavello 2001).

The differences between the sampling areas and their relationship with the months could also be due to monthly temperature changes since it has been shown that temperature is a controlling factor for the growth of *C. chamissoi* (Bulboa and Macchiavello 2001). It was observed that the highest biomass was reported in September 2021 (18.9°C) compared to March 2022 (24.8°C), the month during which the highest sea surface temperature and biomass equal to zero were recorded. This is attributed to the fact that lower temperatures favor the growth of *C. chamissoi in situ* (Bulboa and Macchiavello 2001), while during the warm months, there is an increase in grazing, epiphyte proliferation, and excess radiation, which generate bleaching, detachment, and destruction of fronds (Macchiavello et al. 2003). Complementary studies are necessary that consider epiphytes in the studied species, a factor that can also affect the growth of this species (Uribe et al. 2018).

On the other hand, the differences in carbon capture between September 2021 and 2022 show that the oceanographic conditions to which each month is subjected also play an essential role in carbon capture. During May 2022, shallow subtropical waters appeared close to the coast between Pisco and

San Juan de Marcona (IMARPE, 2022), which may have generated stratification, change in settlement, and alteration of biomass growth. The variation could also be due to the extraction pressure, which plays an important role in the study area. When *C. chamissoi* is extracted massively, the recovery of the populations in the different sampling areas can be affected. However, the differences in carbon capture between September 2021 and 2022, show that the oceanographic conditions each month also play an essential role in carbon capture.

Species from various coastal marine ecosystems have been studied, reporting carbon captures of 3.09 t C ha $^{-1}$ for the macroalgae *L. hyperborea* in warm regions and 9.72 t C ha $^{-1}$ in cold regions (Pessarrodona et al. 2018), and 4.31 ± .56 t C ha $^{-1}$ for the macroalga *L. trabeculata* (Aller-Rojas et al. 2020), while the seagrass *Thalassia testudinum* recorded a capture between 4.6 t C/ ha^{-1} and 3.5 t C ha^{-1} (Acosta-Chaparro et al. 2022). On the other hand, the carbon captures of coastal wetland species, such as *Schoenoplectus californicus* "totora" were 28.9 t C ha^{-1}, 18.6 t C ha-1 for *Scirpus americanus* "junco", 17 t C ha-1 for *Paspalum vaginatum* "grass salt" stores and 6.1 t C/ha for *Salicornia fruticosa* "salicornia" (Contreras and Carranza 2007). According to our study, *C. chamissoi* had a maximum potential catch of 1.86 t C ha^{-1}, a value lower than that found in the species mentioned above and the dynamics of which differ from our species, since the above species do not present extraction cycles.

In our context, the population of *C. chamissoi* is extracted periodically, with the capture of carbon over a period (related to its life cycle, maturity, and extraction). Despite this, they do not contribute to carbon capture since this element does not end up on the seabed. In this context, it is necessary to study the transport of carbon that at some point was part of the macroalgae biomass. In Peru, there is no industrial use of this algae, since there are no companies performing the extraction of carrageenan; therefore, it is exported as raw material and imported in the form of carrageenan (Arbaiza et al. 2019). In 2020, Peru exported 97.95 t of DB *C. chamissoi* for industrial purposes (mainly carrageenan extraction), with the United States, France, and Canada being the main destinations. Likewise, 5.3 t of DB were exported for direct human consumption, with the main destinations being China, Taiwan, and Japan (Avila-Peltroche and Villena-Sarmiento 2022). Locally, this resource is in high demand as it has been part of the Peruvian diet since pre-Inca times (Acleto 1986), and is a main component of highly consumed seafood dishes in the country (Diaz et al. 2021).

The carbon that is captured by *C. chamissoi* returns to us either converted into carrageenan or through direct consumption. Subsequently, due to our physiological processes, it is eliminated as CO_2 into the atmosphere, returning to the carbon cycle. Then, the algal populations or other ecosystems that serve as a carbon sink fix the CO_2 again, thus generating a cycle that is repeated periodically. After this process, it is no longer considered blue carbon.

Currently, there is a Fisheries Management Regulation for macroalgae, but there is no specific regulation for *C. chamissoi*. The results of the present investigation on algal biomass allow evaluation of the sustainability of this resource in regard to availability and use (Magill et al. 2019) and can aid the Ministry of Production together with the Regional Directorate of Production of Ica and the Institute of the

Sea of Peru to develop sustainable extraction schemes, especially in the Protected Natural Area of Paracas.

This study details the carbon capture of an algal meadow as a possible mitigation measure against climate change (Cuba et al. 2022), and thus, non-extracted algal populations could be included in future carbon inventories prepared by the Ministry of the Environment of Peru. This inclusion will be conditioned by the limited and sustainable resource extraction, as well as the quantification of algae extraction and its reincorporation in the calculation. This research responds to strategies previously identified for the development of the blue economy in Peru (McKinley et al. 2019), and the data will be added to those recently obtained in other vegetated marine-coastal ecosystems (Aller-Rojas et al. 2020) for the better understanding of these ecosystems.

We did not differentiate the reproductive phases and sizes for calculating biomass and carbon capture. The methodology used in this study assumed that the percentage of carbon is the same throughout the year, without considering seasonal influences (environmental variables such as physical parameters). Under these premises, it has been verified that there are significant differences in density and weight between vegetative plants and plants with carpospores (Uribe et al. 2018). In addition, it has been observed that environmental variables influence the carbon storage of kelp beds (Aller-Rojas et al. 2020). Therefore, we suggest that future studies include heights, sexual proportions, and physical parameters. The present study is the first to characterize the algal population and the carbon capture of *C. chamissoi* under a dynamic of massive extraction during an entire cycle (Fig. 4), laying the foundations for future investigations.

Conclusion

The distribution and area of each sampling zone identified varied monthly. The highest algal biomass was reported in September 2021 with 504.2 t of wet biomass, with the % DB being 10 ± 0.01 and the % C was 25.83 ± 0.57. The Laguna Grande coastal lagoon presents a dynamic in which the cyclical processes of total extraction of the algal biomass explain the carbon capture, which was highest in September 2021 with 13 t C. Significant differences were found in the capture of carbon, between the sampling areas, months of the year and the interaction between these last two variables.

The results of this study allow the evaluation of resource availability and the proposal of sustainable extraction schemes. Additionally, carbon estimation can be included in the regional adaptation and mitigation strategies against climate change.

Declarations

Funding

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Competing interests

The *C. chamissoi* biomass extracted by artisanal fishermen from the study area is used by the company ALGAEX S.A. This work is the product of the thesis project of AC to obtain the professional title of Marine Biologist.

Availability of data and material

The datasets generated during and/or analysed during the current study are available are within the supplementary material.

Code availability

Not applicable.

Authors' contributions

The authors responsibilities were as follows–ACA, STG and HA: designed and conducted the research. ACA an HA wrote the manuscript and analysed the data; ACA had primarily responsibility for the final content of the manuscript; and all authors: edited, read and approved the final manuscript.

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Figures

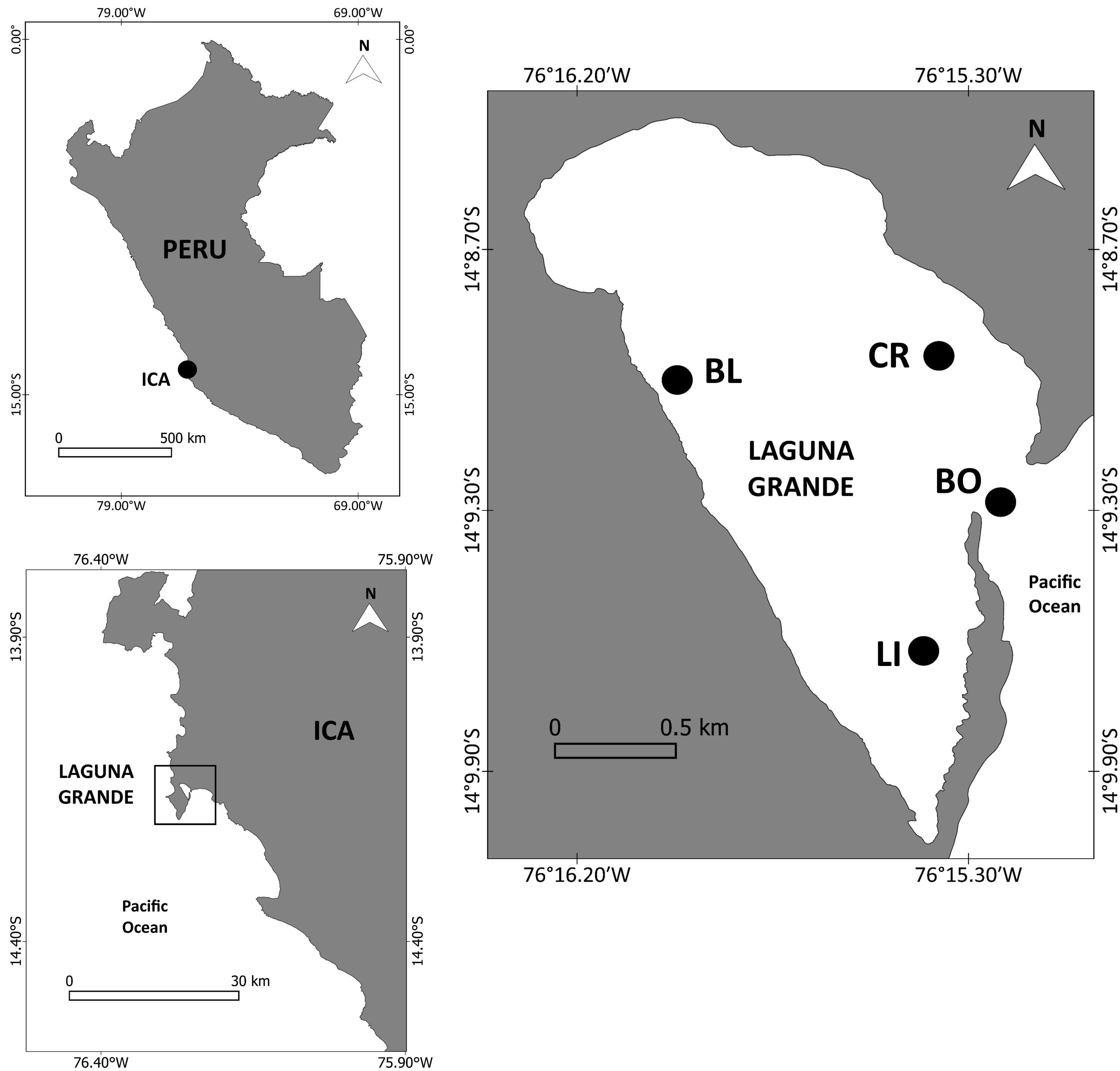

Figure 1

The location of Laguna Grande in a) Peru and b) the Ica Region. In c), the sampling area is shown, indicating the four sampling zones: Bocana (BO), La Isla (LI), Bajada de León (BL), and Criadero (CR)

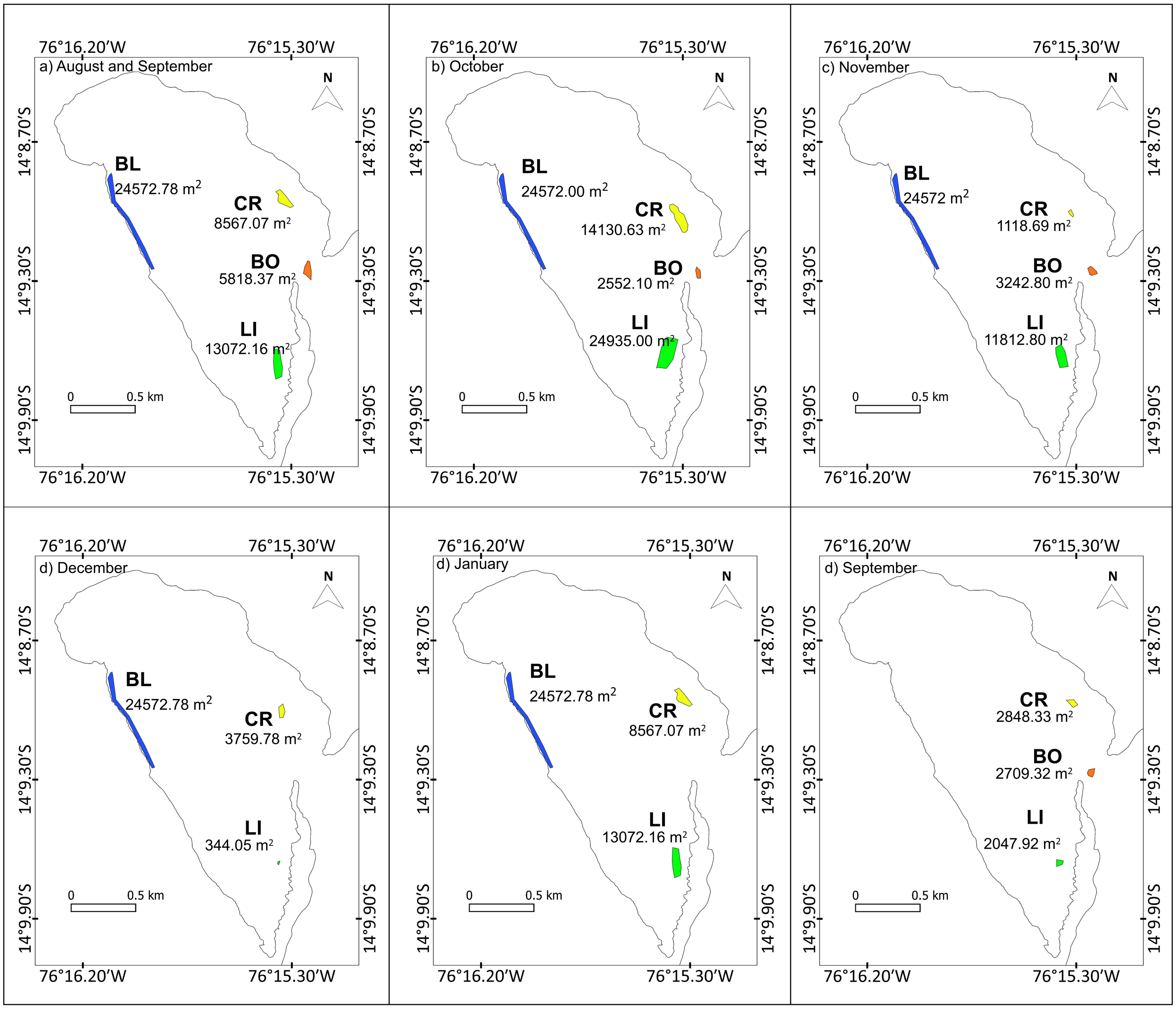

Figure 2

Distribution and area of the orange Bocana (BO), green La Isla (LI), blue Bajada de León (BL), and yellow Criadero (CR) sampling zones. a) Sampling of August and September 2021; b) Sampling of October 2021; c) Sampling of November 2021, d) Sampling of December 2021; e) Sampling of January 2022; f) Sampling of September 2022. The samplings that do not appear in the figures are those without algal biomass

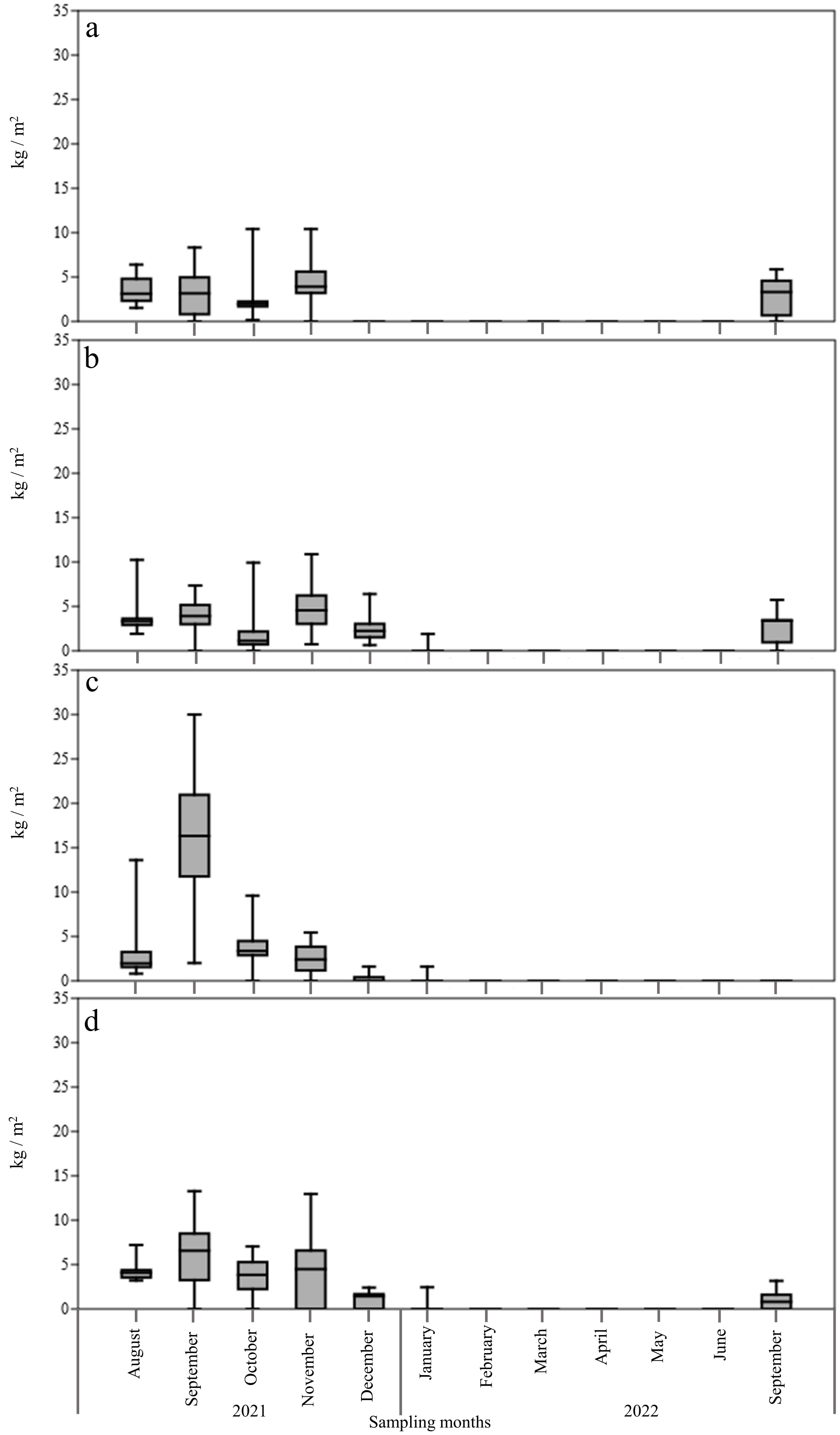

Figure 3

Boxplot chart of the wet biomass (kg/m^2) was found in the four sampling areas. a) Bocana, b) The Island, c) Bajada de León, and d) Criadero. Error bars indicate standard deviation

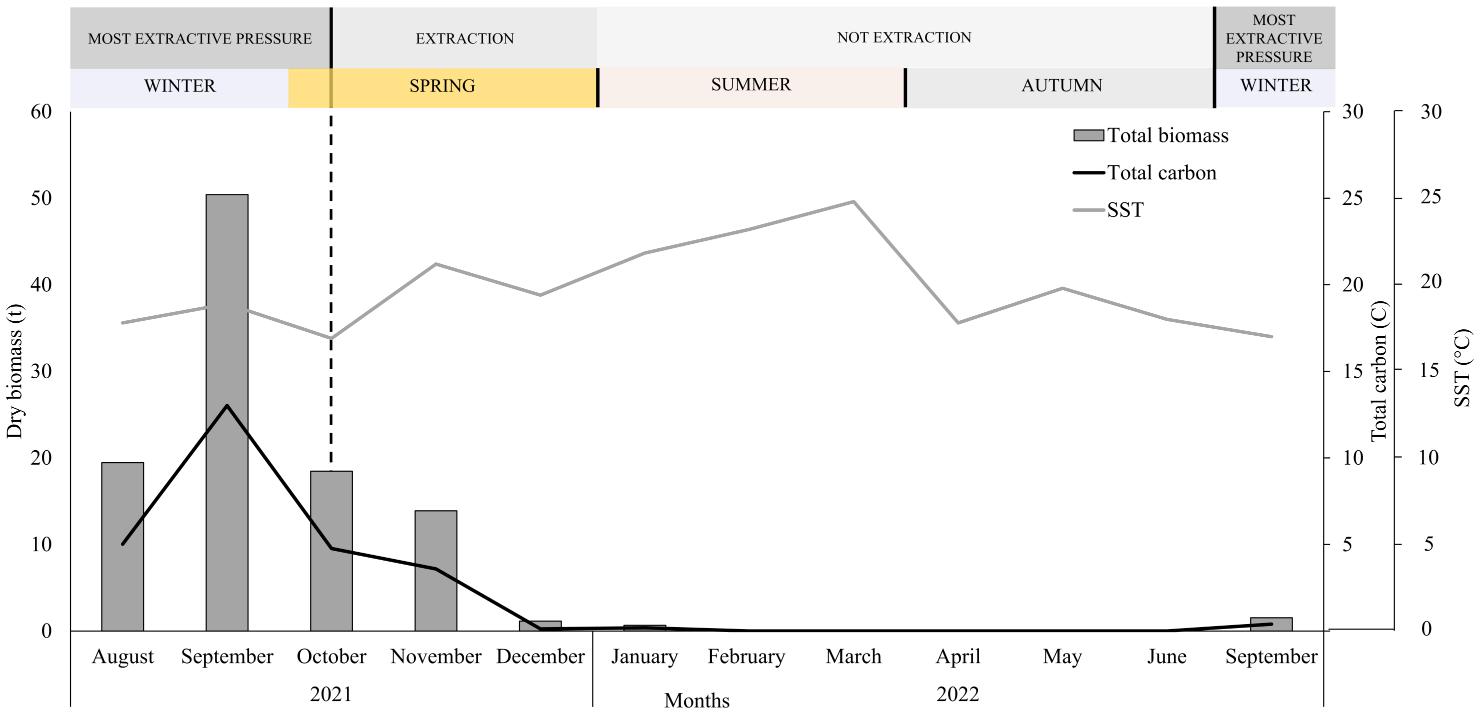

Figure 4

Total carbon capture (t C), dry biomass (t) of *C. chamissoi*and its relationship with the seasons of the year, the extractive processes of the resource, and the sea surface temperature (SST)

Supplementary Files

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