Facultad de Ciencias
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Universidad de La Laguna

Patrones temporales y procesos de las poblaciones de *Gongolaria abies – marina* en la isla de Gran Canaria (Atlántico-este).

Temporal patterns and drivers of *Gongolaria abies – marina* populations in Gran Canaria Island (eastern Atlantic).

Julián Cabana Gandiaga

Máster en Biología Marina: Biodiversidad y Conservación

Septiembre de 2022

Universidad de La Laguna	**AUTORIZACIÓN DEL TUTOR/ES**	

El Dr. **José Antonio Pérez Pérez**, Profesor Ayudante Doctor de la Universidad de La Laguna y el Dr. **Fernando Tuya Cortés**, Profesor Titular de la Universidad de Las Palmas de Gran Canaria, como Tutor Académico y Tutor Externo, respectivamente,

DECLARAN:

Que la memoria presentada por **D. Julián Cabana Gandiaga** titulada **"Patrones temporales y procesos de las poblaciones de *Gongolaria abies – marina* en la isla de Gran Canaria (Atlántico- este)",** ha sido realizada bajo su dirección y consideran que reúne todas las condiciones de calidad y rigor científico requeridas para optar a su presentación como Trabajo de Fin de Máster, en el Máster Oficial de Postgrado de Biología Marina: Biodiversidad y Conservación de la Universidad de La Laguna, curso académico 2021-2022.

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Este trabajo va dedicado para ti Mamá

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ABSTRACT

In the Canary Islands, many marine species are suffering the consequences of the human impacts; one of those species is the alga *Gongolaria abies – marina,* wich has suffered, since 1980, a massive decline in Gran Canaria Island, losing more than the 90 % of the cover. In this work, we updated the regression of this macroalga. Then, we determined the factors that better predicted the presence of this species at large scale (coastal perimeter) and at small scales, by considering presence as "open rock" or in "crevices". This species occupied in 1980 a 47% of the coastal perimeter and a 14,08 % in 2016, nowadays, the alga occupies only a 4,39 %. Our data showed that the small- scale presence in "open rock" was large when the sector/cell perimeter occupied by the species was large. We also found that sea water temperature and wave power have significantly contributed to explain the decline of this species, so a high wave power promote the persistence of the species, while zones with high temperatures negatively affected the alga and limited its presence in "open rock". In brief, this study demonstrated that *G. abies-marina* resist in "crevices" as a mechanism of self-protection.

Keywords: *Gongolaria abies – marina,* open rock, crevices, regression, temperature, sector/cell.

RESUMEN

En Canarias, muchas especies marinas están sufriendo las consecuencias de los impactos humanos; una de esas especies es el alga *Gongolaria abies – marina,* que ha sufrido, desde el año 1980, un declive masivo, perdiendo más del 90 % de su cobertura. En este trabajo, actualizamos la regresión de esta macroalga. Luego, determinamos cuáles son los factores que mejor predijeron la presencia de esta especie a gran escala (perímetro costero) y a pequeña escala, considerando presencia en "campo abierto" o "en grietas". Esta especie ocupaba en 1980 un perímetro costero del 47% y un 14,08% en 2016, en la actualidad sólo ocupa un 4,39%. Nuestros datos mostraron que la presencia a pequeña escala en "campo abierto" era grande cuando el perímetro de la ocupado por la especie era alto. También encontramos que la temperatura del agua y la potencia del oleaje han contribuido de manera significativa a explicar la disminución de la especie, por lo que un alto potencial del oleaje promueve la persistencia de la especie, mientras las zonas con altas temperaturas afectan negativamente al alga y limitan su presencia en "campo abierto". En resumen, este estudio demostró que *Gongolaria abies – marina* resiste a pequeña escala en "grietas" como un probable mecanismo de autoprotección.

Palabras clave: *Gongolaria abies – marina,* campo abierto, grietas, regresión, temperatura, sectores.

1. INTRODUCTION

The Canary Islands are a “hot spot” of marine biodiversity in the North Atlantic (Sansón *et al.,* 2001; Valdazo *et al.,* 2017). In these islands a great variety of species can be found, from microalgae, small mollusks, and fishes to cetaceans. The high number of marine species appears to be the result of the combined effects of the geographical position of the archipelago, its prevailing oceanographic conditions and paleoclimatic events (Prud'homme van Reine and van den Hoek, 1990; Silva, 1992; Prud'homme van Reine, 1998; Haroun *et al.,* 2002). The Canary Islands have a rich flora with co-occurrence of floristic elements from the Mediterranean Sea, the Tropical Western Atlantic Ocean (mainly the Caribbean Sea) and the Warm Temperate North Atlantic coasts (both European and American coasts), being this flora composed of 711 species, which are distributed as follows: 59 Cyanophyta, 385 Rhodophyta, 125 Chromophycota, 117 Chlorophyta, 3 seagrasses and 22 fungi (Haroun *et al.,* 2002). The species of algae presents in the archipelago play a key role in the water ecosystems of this part of the Atlantic Ocean.

The brown algae *Gongolaria abies-marina* (S.G. Gemelin) C. Agardh has been considered the most abundant fucoid species on rocky shores of the Canarian Archipelago (Wildpret *et al*., 1987, Tuya and Haroun, 2006; Valdazo *et al.,* 2017), typically forming extensive stands in the lower intertidal to shallow subtidal zone of moderately exposed and exposed rocky reefs (Wildpret *et al*., 1987; Medina, 1997; Valdazo *et al.*, 2020). Marine forests of large brown macroalgae, mostly belonging to the orders Fucales and Laminariales, are unique habitats which support a great variety of organisms in coastal zones worldwide and are comparable to terrestrial forests for the services they provide (Steneck *et al*., 2002; Valdazo *et al.,* 2020). Moreover, Cystoseira spp. can produce potentially bioactive metabolites like fatty acids, steroids, polysaccharides and terpenoids, that have diverse benefits for humans (De Souza *et al.,* 2017; Orlando-Bonaca *et al.,* 2021). Also, numerous species of Cystoseira have antiviral, antibacterial, antioxidant, anti-inflammatory, and antifungal activities (Mhadhebi *et al.,* 2011; Vizetto-Duarte *et al.,* 2016; De Souza *et al.,* 2017; Orlando-Bonaca *et al.,* 2021).

Gongolaria abies - marina is a perennial, monoecious alga, which produce sperm and large no mobile eggs in hermaphroditic conceptacles. It has external fertilization few hours after the gamete release (Guern, 1962; Valdazo, 2021).

Like other species of the genus, thalli are negatively buoyant, and the zygotes are heavy; for that reason, they tend to sink near the parents (Guern, 1962; Valdazo *et al*., 2020). Therefore, the genus or the species have a low dispersal ability (Mangialajo *et al.*, 2012; Valdazo *et al.*, 2020).

The genus Cystoseira (genus to which actual *Gongolaria abies - marina* belonged) C. Agardh (Fucales, Phaeophyta) is distributed in temperate and subtropical coasts around the world, although 80% of the species live in the Mediterranean Sea (Oliveras and Gómez, 1989; Valdazo *et al.*, 2017). In the Mediterranean and the adjacent Atlantic Ocean, species of the genus Cystoseira are the main group of habitat-forming macroalgae, from the littoral to the lower limit of the euphotic zone (Giaccone *et al*., 1994, García-Fernández and Bárbara, 2016; Valdazo *et al.*, 2017) and the structure of this algae is influenced by different environmental variables, like temperature (Tuya *et al.*, 2012; Valdazo *et al.*, 2020), light availability (Creed *et al.*, 1998; Valdazo *et al.*, 2020), nutrients (Piazzi & Ceccherelli, 2017; Valdazo *et al.*, 2020) and wave intensity (Engelen *et al.*, 2005; Valdazo *et al.*, 2020).

Figure 1. Community of *Gongolaria abies – marina* in Banderols (north of Gran Canaria)

Perennial brown macroalgae communities play a very important role in the ecology in the coastal ecosystems, being one of the main primary producers and recycling the nutrients of the water (Ballesteros, 1989, 1992; Sales & Ballesteros, 2012; Blanco – Magadan, 2020). It offers a complex structure that provides habitat for a large amount of algae and invertebrates (Belegratis *et al*., 1999; Pardi *et al*., 2000; Montesanto & Panayotidis, 2001; Sales & Ballesteros, 2007, 2009, 2012; Sales *et al*., 2012; Blanco – Magadan, 2020) providing food, shelter and breeding zones for different species (Cheminée *et al*., 2013, 2017; Blanco – Magadan, 2020) facilitating invertebrate recruitment and growth and providing protection from wave action, desiccation and visual predators (Chapman, 1995; Wahl *et al*., 2011; Dijkstra *et al*., 2012; Jueterbock *et al.,* 2013) and also modulate the structure of the associated benthic community (Mineur *et al.,* 2015; Falace *et al.,* 2018). These large perennial macroalgae are considered as "engineering species" (Jones *et al*., 1994; Valdazo *et al.*, 2017). Besides, macroalgae beds form an important sink for CO2 emissions (Gao and McKinley, 1994; Muraoka, 2004; Chung *et al*., 2011; Jueterbock *et al.,* 2013), sequestering about 1 gigaton of carbon per year (together with sea grass beds) (Gao and McKinley, 1994; Chung *et al*., 2011; Jueterbock *et al.,* 2013), which is the same of about a quarter of the current yearly atmospheric carbon increase (Denman *et al*., 2007; Jueterbock *et al.,* 2013).

Coastal ecosystems are in danger because of the impacts worldwide done by the human pressure. The Canary Islands, a "hot spot" of biodiversity (Sansón *et al.,* 2001; Valdazo *et al.,* 2017), is threatened by human impacts like pollution, overfishing, occupation of the coast and progressive tropicalization (Riera *et al.,* 2015*;* Valdazo *et al.,* 2017*).* Specially species that belong to the genus Cystoseira have a high sensitivity to anthropogenic impacts. Due to such sensitivity to external impacts, many species of Cystoseira are considered indicators of high-quality waters. Habitat destruction, pollution, eutrophication, species introduction, overfishing and global warming, which often get together, affecting species, ecosystems, and their ability to provide ecosystem services (Halpern *et al.,* 2008; Valdazo *et al.,* 2017). Besides, factors like warming and ocean acidification are causing the reorganization of local communities as species are added or deleted and as interactions among species change in importance (Wootton *et al*., 2008; Harley, 2011; Harley *et al.,* 2012).

Because of all these impacts, many systems have turned from complex and productive to simpler, less-productive habitat such as barrens, turf-forming algae, and other ephemeral opportunistic seaweeds, impacting the provision of ecosystem services (Munda IM, 1993; Boudouresque, 2004; Marzinelli *et al.*, 2014). For that reason, all species that belong to the Genus Cystoseira (except *C. compressa*) are included in the "Spanish catalog of Endagered species" (Real Decreto 139/2011) (Blanco – Magadan, 2020). Besides, *Gongolaria abies - marina* is in the list of species of interest for the Canarian ecosystems (Law 4/2010; Canary catalog of Protected Species).

Eutrophication is a serious and increasing problem in coastal waters worldwide. Wastewater discharges close to the coastline produce deterioration in water quality and affects rocky shores macroalgal communities (Bellan-Santini, 1968; Borowitzka, 1972; Munda, 1974; Littler and Murray, 1975; Arévalo *et al.*, 2007). Nutrient and organic enrichment because of domestic wasted is nowadays one of the main reasons that explain the deterioration of marine nearshore ecosystems (Fletcher, 1996; Arévalo *et al.*, 2007) which causes changes at the population, community or even at the ecosystem level (Soltan, 2001; Arévalo *et al.*, 2007).

Geppi *et al.*, (2022) reported evidence of the effects of warming waters on species of brown algae like *Gongolaria abies – marina,* indicating in their study that, *Gongolaria abies-marina* presented morphologic changes caused by the temperature before that other alga like *Cystoseira compressa* or *Cystoseira humilis*, showing a clear sensitivity to this stressor and a smaller tolerance to warm waters than other species; Geppi *et al.*, (2022) also said that the fact that the largest algae (of those studied in their work) was the first to be affected by the temperature, could be an indicated that the species have an inverse proportionality between the size of the structure and the tolerance temperature limit (Bennet *et al.*, 2018*).* Also, Alfonso *et al.*, (2022), reported that the length of the thallus of *Gelidium canariense* was reduced by half during the last 40 years; this thallus shortening coincided with a significant decrease in the number of reproductive structures in both species of Gelidium (*G. canariense and G. arbuscula).* These morphological changes coincide with an important rise of sea surface temperature, sea surface air temperature and ultraviolet radiation in the study area. When well-structured and diverse ecosystems are gone, that facilitates the appearance of less complex habitats, like filamentous algal turfs, ephemeral seaweed assemblages and barren ground dominated by encrusting algae and sea urchins (Benedetti-Cecchi *et al.*, 2001, Ling *et al.*, 2015; Valdazo *et al*., 2017).

Despite the implementation of important conservation efforts, the main part of the degraded ecosystems has not recovered, emphasizing the urgency to develop a plan to restore endangered habitats (Marzinelli *et al.*, 2014). The efforts and the work which has been doing for the conservation of the marine ecosystem is turning to another goal and it is not conservation anymore, nowadays, we are starting to work for restoration, because we are losing species worldwide caused by climate change, human pollution and many others and we cannot conservate if we haven't got anything for that purpose.

Another and a very important problem nowadays which affects the macroalgae communities are the high densities of herbivorous organisms, like *Diadema africanum* present in al the Canary Islands waters or different kind of fishes. Like says Tuya *et al.*, (2004), their study represents another case where low abundance and biomass of top predatory fish seem to be related to high densities of sea urchins and therefore, low cover of macroalgae produced by the voracity of those urchins. The overgrazing produced by sea urchins is responsible, together with other locals and global stressors, for the loss of Cystoseira beds and the next transformation of this ecosystems to barren grounds (Pinnegar *et al*., 2000; Airoldi *et al*., 2014; Bekkby *et al.*, 2020). Despite this problem has been minored in the last decade across the Canary Islands (Sangil & Hernández, 2022), herbivory is a key driver of macroalgae.

Figure 2. Sea urchin barren of *Diadema africanum* in Tufia, Gran canaria.

In addition, there is also the herbivory of some fishes whose main food resource are the macroalgae. In sublittoral communities like the macroalgae, the action done by the herbivorous organisms is one of the most important mechanisms that determinate macrophyte species abundance and distribution (Cyr & Pace, 1993, Burkepile & Hay, 2006; Vergés *et al.,* 2009). Gradients in herbivory can really contribute to the vertical distribution of macrophytes (Witman, 1987, Morrison, 1988; Vergés *et al.*, 2009).

Because of the redistribution of species and novel biological interactions caused by climate change (Blowes *et al*., 2019) herbivory in temperate reefs is rising. The abundance and diversity of different species of herbivores in several temperate regions of the world are increasing because of the rise of the range extension of tropical species because of the intensification of warm currents that transport tropical propagules to higher latitudes (Vergés *et al*., 2014). In addition, the strength of predator-prey interactions that alter the abundance, biomass, and productivity of primary producers indirectly via trophic cascades is stronger in aquatic compared to terrestrial systems (Shurin *et al*., 2002).

Due to high pressures and intensities of herbivory, macrophytes are likely to persist if they are unpalatable to consumers or settle in habitats which are inaccessible to herbivores (Lubchenco & Gaines, 1981). This habitats or environmental factors that enhance resistance and resilience in communities that are exposed to biophysical disturbances can be considered as “refugia” (Sedell *et al*., 1990). In this way, substratum topography offers protection to different organisms against multiple kinds of disturbance, like showed by accumulating studies from terrestrial (Reader, 1992) and aquatic systems (Bergey, 2005, Brandl *et al*., 2014).

Examples of refugia against herbivory exist in different places, including land (Beschta, 2005), freshwater (Bergey, 2005), coral reefs (Bennett *et al.*, 2010; Brandl *et al.*, 2014; Puk *et al*., 2020) and temperate reefs (Franco *et al*., 2015). An example of this activity can be seen in encrusting algae of the genus Hildenbrandia, which are successful against herbivory because propagules tend to grow out from small cracks and crevices inaccessible to grazers (Underwood, 1980). In the same way, Bergey, (2005), described the importance of crevices to increase algal recovery after disturbance, and Brandl *et al*., (2014) showed the important role of crevices for early life stages of both coral and macroalgal populations.

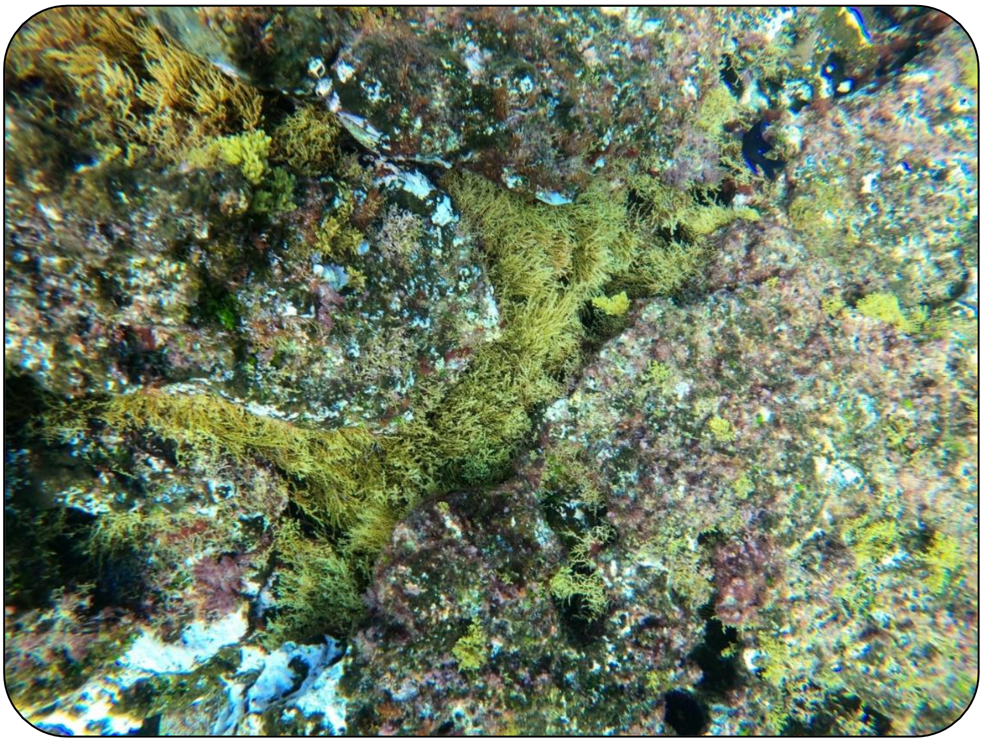

Figure 3. Example of *Gongolaria abies – marina* in crevices.

2. OBJETIVES

- To update the current conservation status of the *Gongolaria abies – marina* populations in Gran Canaria Island, to compare our results with previous cartographic studies and estimate the regression of the species.
- To determinate what are the environmental factors that predict, and therefore, affects, the large- and small-scale presence of *Gongolaria abies - marina* in Gran Canaria Island.

3. MATERIALS AND METHODS

- 3.1. Study area

Our study was carried out in the island of Gran Canaria, all along the coast of the island (Fig. 4). Gran Canaria island (28°51'N, 15°36'W) is found 200 km off the northwest African coast and it is in the middle of the Canary Islands. The shape of this island is almost circular with 256 km of coastal perimeter. In this island we can found different kind of coasts, from littoral with coastal platforms and beaches at the south and east to cliffs, especially at the north and west side of it (Valdazo *et al.,* 2017).

The interaction between the cold Canary current, which goes through from NNE to SSW and the African NE upwelling create a longitudinal thermic gradient between colder eastern islands (Lanzarote, Fuerteventura) and the warmer western islands (La Palma and El Hierro) (Barton *et al*., 1998; Davenport *et al*., 2002; Cuétara, 2020)

- 3.2. Sampling

We performed surveys all around the island of Gran Canaria. We divided the island in 28 "GRIDS" (cells) or sectors of 5x5 km (Fig. 4), following Valdazo *et al.,* (2017), which have different values of wave exposition, HAPI index and temperature changes. Field surveys were done between January 2022 and May 2022, trying to reach that maximum development of the species between the months of march and October. In this work, we carried out a distribution study of the species *Gongolaria abies - marina,* focusing specially on the small- scale presence of this alga ("open rock" or "crevices"). In this study, we did a distribution map of this species, and we studied in what kind of habitat it was situated in each sector. We worked the intertidal zone of the coast of the whole island, so in this way we covered the distribution bathymetric range of the aim species. Depending on the features of the coast, we did the field work by foot or on boat (in this case by snorkeling). We used a high-quality camera to take pictures and videos of the species; this camera has incorporated GPS, so we could georeferenced each sample during the study and associate the habitat to the coordinates. Depending on the size of the patches of *Gongolaria abies - marina,* we classified them in three categories: points (1 m to 2m), lines (long band of many meters of the algae along the coast) or a polygon (more than 4 m^2) (Fig. 5). All the points found from 1m to 2m where in a hiding habitat, under the rocks or in crevices, for that reason we considered that all the "points" were affected by the "refugia effect"; on the other hand, the "lines" and "polygons" were much bigger than the “points”, Because of their size they cannot being hiding under the rocks but they were in open field, so we classified both lines and polygons like open rock habitats.

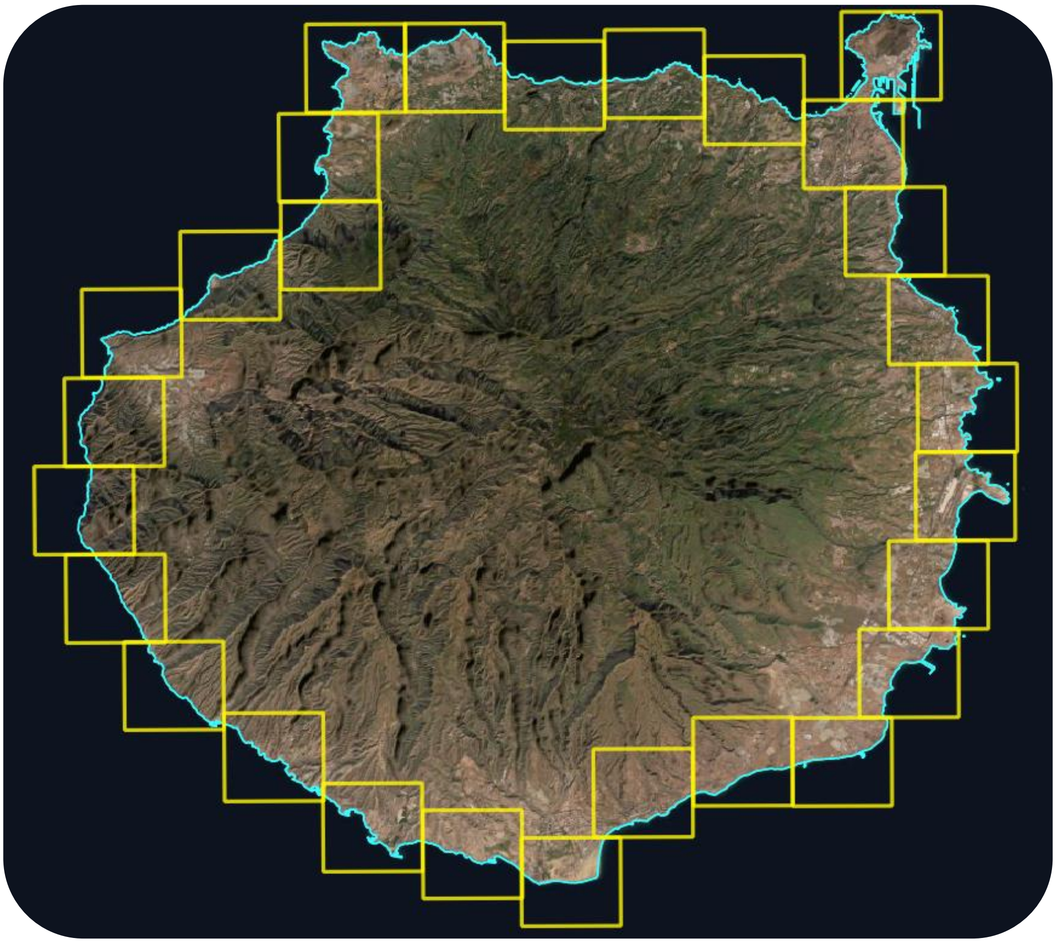

Figure 4. Gran Canaria island divided in the 28 sectors which have been studied.

Once all the information on “points, lines and polygons” were taken, we store and analyzed all the data with the open source QGIS software, where we created a Gran Canaria distribution map of the species with all the information. After that, we measured and add all the meters of *Gongolaria abies marina* and then we projected that measure on the total coastal perimeter of the island, so in this way que could obtain what percentage of coastal perimeter of Gran Canaria is occupied by this species to have an update to compare the state of the populations of this alga with past studies, in particular, Valdazo *et al.,* (2017), where the author had already done the comparison between past works about GAB distribution (1980, 2008 and 2016). The data obtained by QGIS also allowed us to calculate the percentage and the presence of GAB, which are either hiding under rock or crevices (refugia effect) or in open field (open rock).

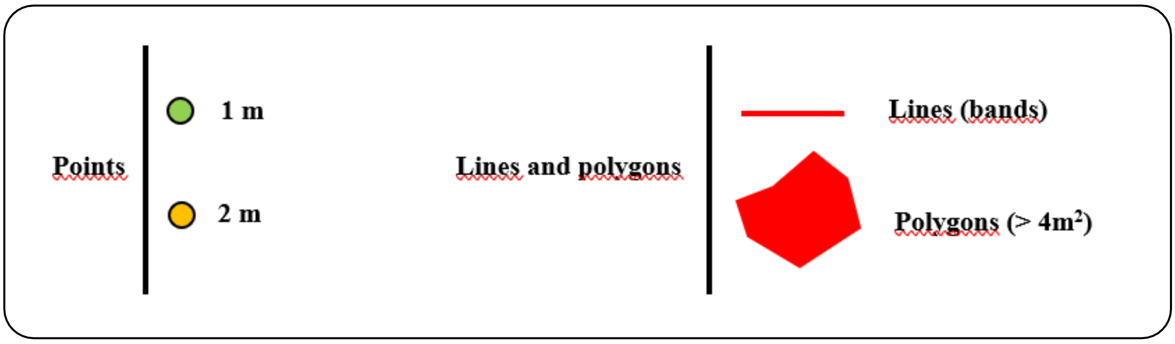

Figure 5. Legend with the classification of the presence of *Gongolaria abies – marina*

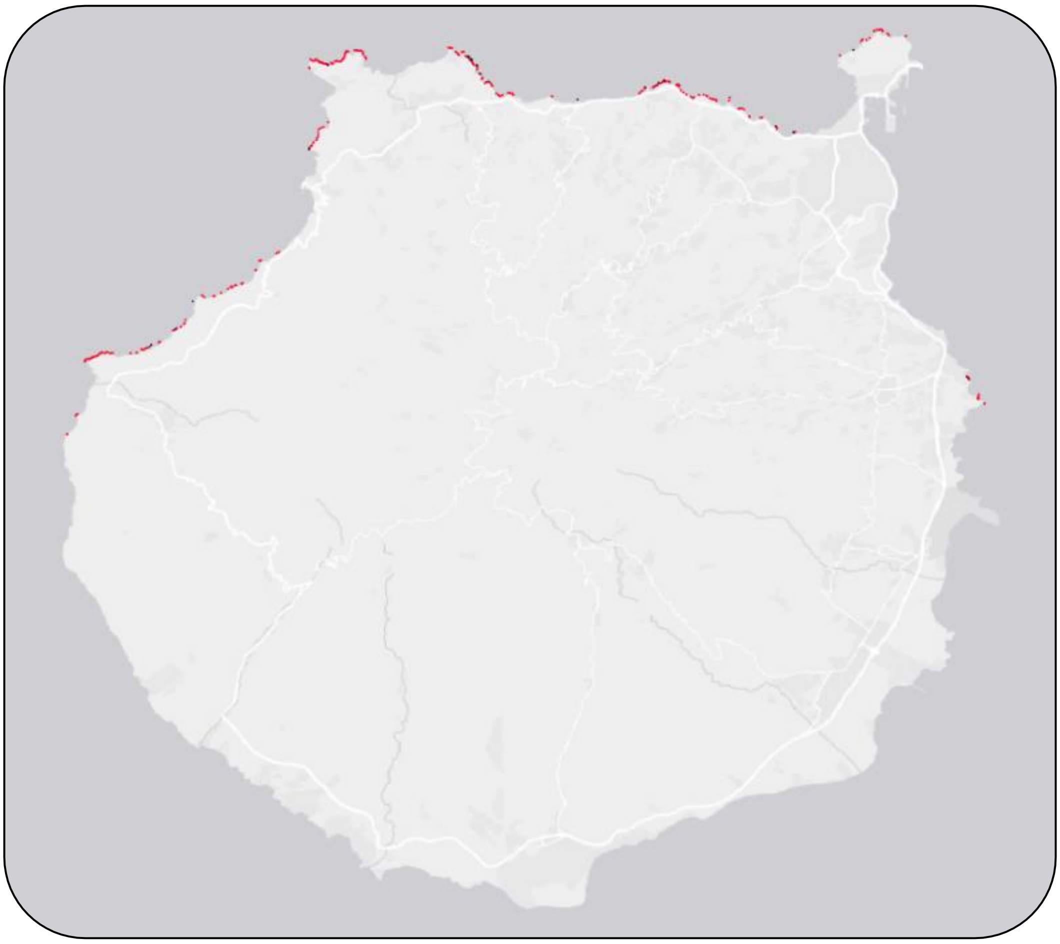

Figure 6. QGIS map of Gran Canaria with all the presence of lines and polygons in red color.

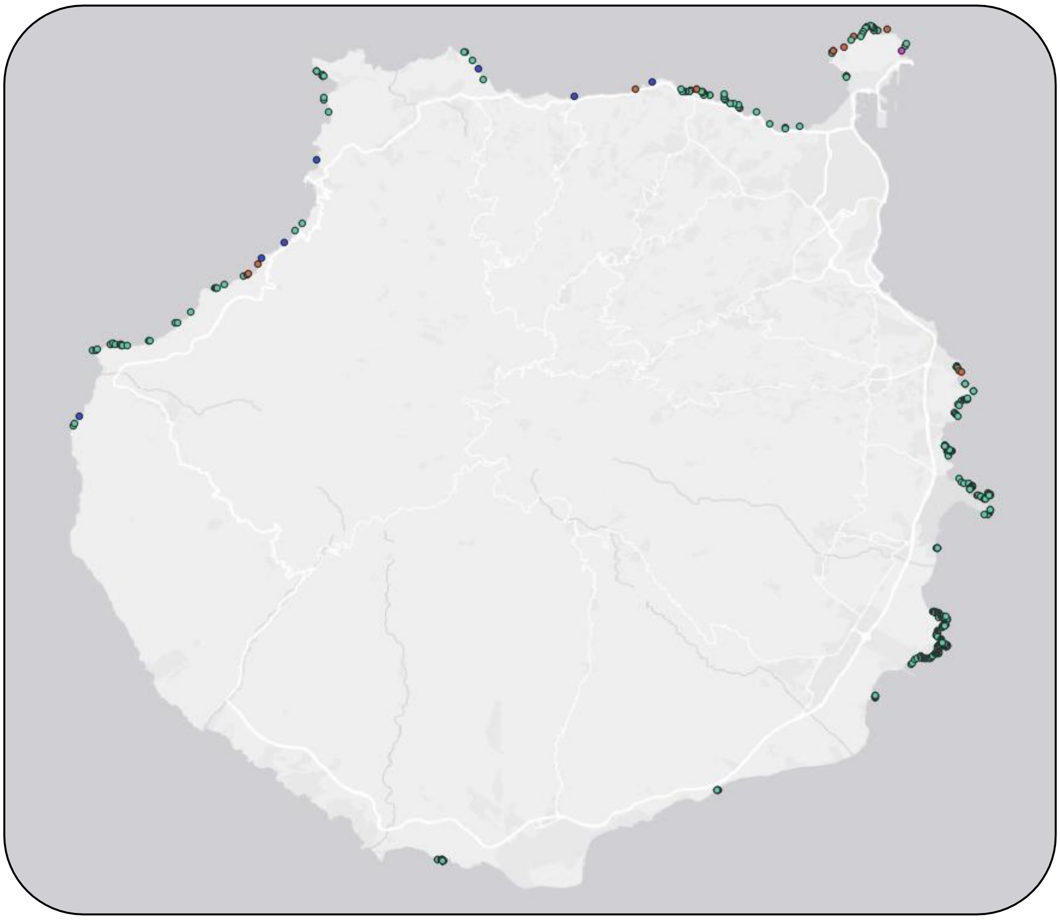

Figure 7. QGIS map with presence of "hidden points" In crevices along the Gran Canaria Island.

- **3.3. Wave power**

Gran Canaria has very different wave exposition depending on which part of the island we are; the morphology of the island and the average current and wind direction (NE) makes that it has hard wave conditions at the north of the island, but very low wave power along the south. We obtained the parameter of wave exposition provide by Chiri, (2011); from this work we used the data of the average wave power of each part of the island (Fig. 8), so, we obtained an exposition index for each sector of Gran Canaria.

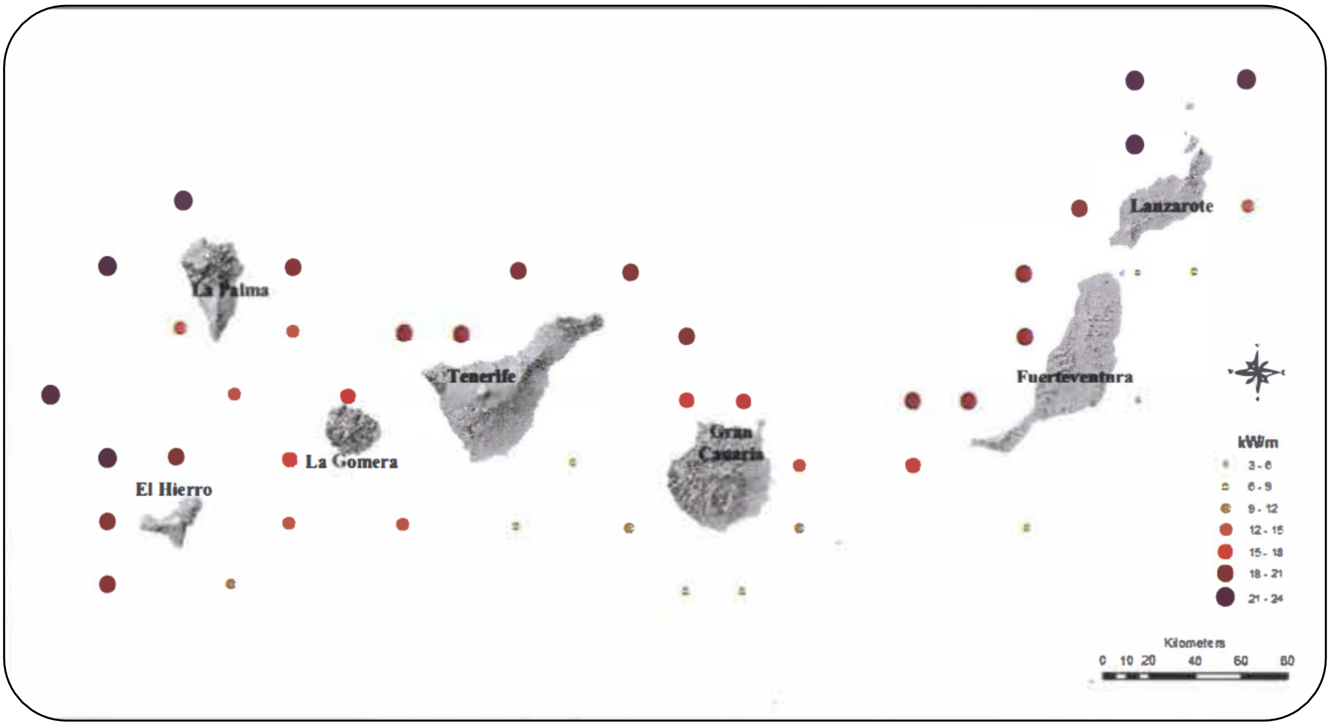

Figure 8. Spatial distribution of the annual average wave power in the Canary islands, as provided by Chiri, 2011. "EVALUACIÓN DEL POTENCIAL ENERGÉTICO DEL OLEAJE EN CANARIAS; VARIACIONES ESPACIO-TEMPORALES"

- **3.4. HAPI index**

In the same way of Valdazo *et al.*, (2017) and Blanfuné *et al.*, *(*2017), we used the Human Activities and Pressures Index (HAPI) to estimate the grade of alteration of the coast of Gran Canaria; the HAPI index was calculated for each of the 28 sectors so we could work the relation between the external pressures and the decline of *Gongolaria abies – marina* meadows.

The HAPI index is formed by six parameters and, combining all of them in a formula $\sum(PSi*ri)/TSj)$, we obtained the HAPI. The parameters needed to calculate this index are three for continental pressures and other three for marine pressures. For continental pressures, we used urban, industrial, and agricultural areas expressed as the percentage of land area covered (CORINE LAND COVER 2022) for each coastal sector or GRID. For marine pressures, we calculated the level of coast artificialization, expressed as the percentage of the artificialized coastline; we estimate the impact of the fish farms expressing the percentage of rocky coastline potentially impacted (500 m radius) and for last, we obtained the sewage outfalls impact expressed also like the percentage of rocky coastline potentially impacted (500 m radius).

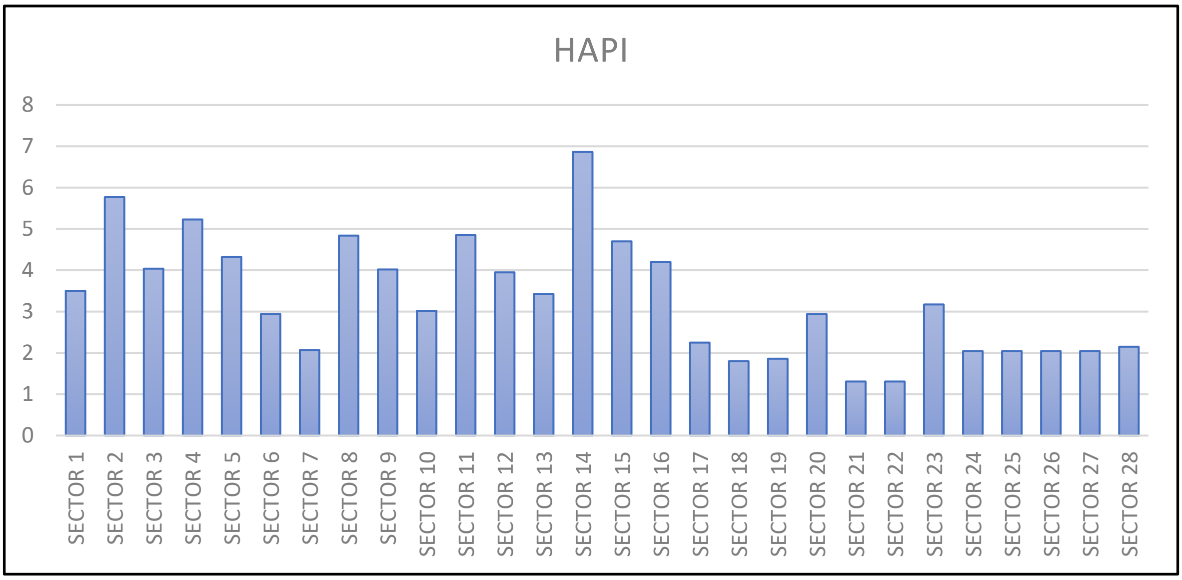

Figure 9. Graphic of the HAPI index in each cell (sector) along Gran Canaria Island.

- **3.5. Temperature data**

To calculate the slope of SST temperature trends over the past 40 years, for each of the 28 sectors along the coastal perimeter of Gran Canaria Island, we obtained the daily sea Surface temperature (SST) from 1982/01/01 to 2022/05/31, the monthly SST from 1982/01 to 2021/12 and the monthly SST anomaly from 1982/01 to 2021/12 and then, with all that data, a simple linear regression was adjusted. The source of the data is the CMEMS (Copernicus Marine Service). The monthly SST data have been generated from daily files in NetCDF format, downloaded from the CMEMS (18500 files).

- **3.6. Statistical analysis**

Using the statistics software R studio, we applied a t student to figure out if there was significant difference between the overall perimeter of *Gongolaria abies marina* in 1987 and 2022; the same procedure was done between the perimeter of the algae in 2022 and the presence of the algae in “open rock” or “crevices” (small scale), to see the relation with this small-scale presence in open rock or crevices. Last, we used a multiple lineal regression (selection “stepwise”) to model what are the factors (environment factors) that predict the percentage of algal coverage, as “open rock” or “crevices”.

4. RESULTS

The presence of *Gongolaria abies – marina* in Gran Canaria Island, in terms of the coastal perimeter occupied, has significantly decreased between 1980s and 2022 (present) (Fig. 10). As we can observe in the figure 10, we see a clear regression of the brown algae species during all these years, being the total extension occupied by *Gongolaria abies - marina* on the coast of Gran Canaria 11,25 km (4,39 %) of 256 km (which is the total perimeter of the coast). This contrast with the 110,07 km (42,99 %) of total extension occupied by *Gongolaria abies - marina* in 1987.

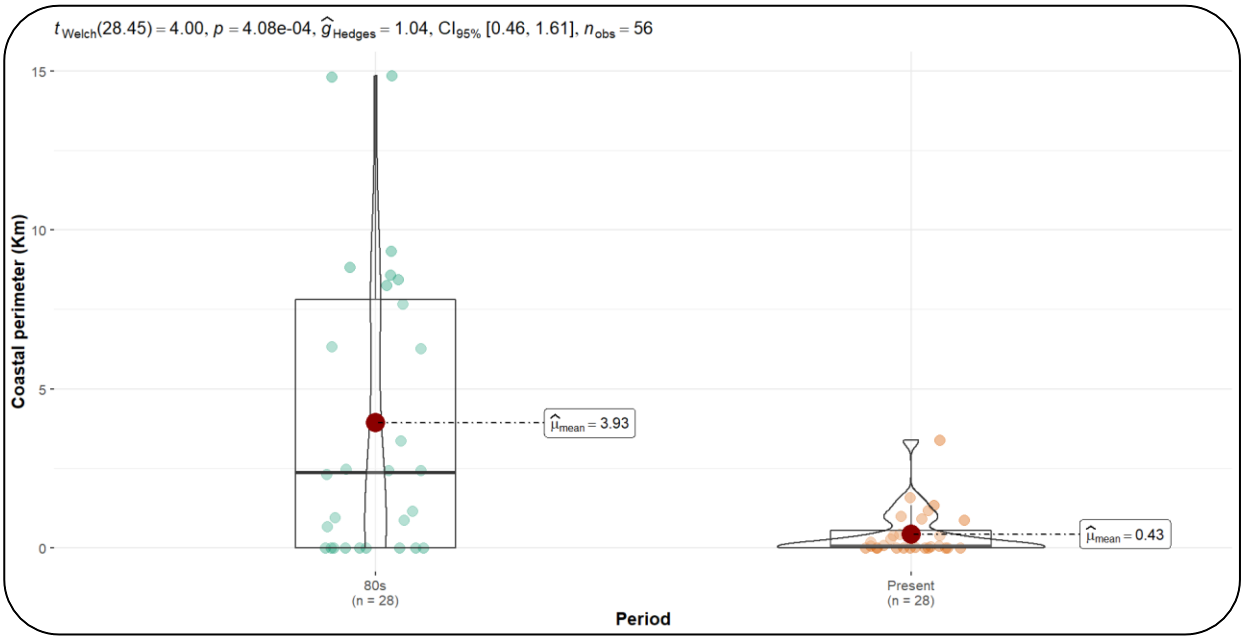

Figure 10. Presence of Gongolaria (Km of coastal perimeter occupied per cell) in the 80s and the present (2022).

While the presence (in terms of small-scall cover) of Gongolaria in open rock increased with the presence of Gongolaria in each cell in 2022 (in terms of the large-scale presence per coastal perimeter) (Fig. 11) (p value=5,40e$^{-04,}$ r^2 = 0,61), the presence (small-scall cover) of Gongolaria in crevices was independent of the presence of Gongolaria in each cell (in terms of the large-scale presence per coastal perimeter) (Fig. 12), (p value= 0,82, r^2 = -0,05).

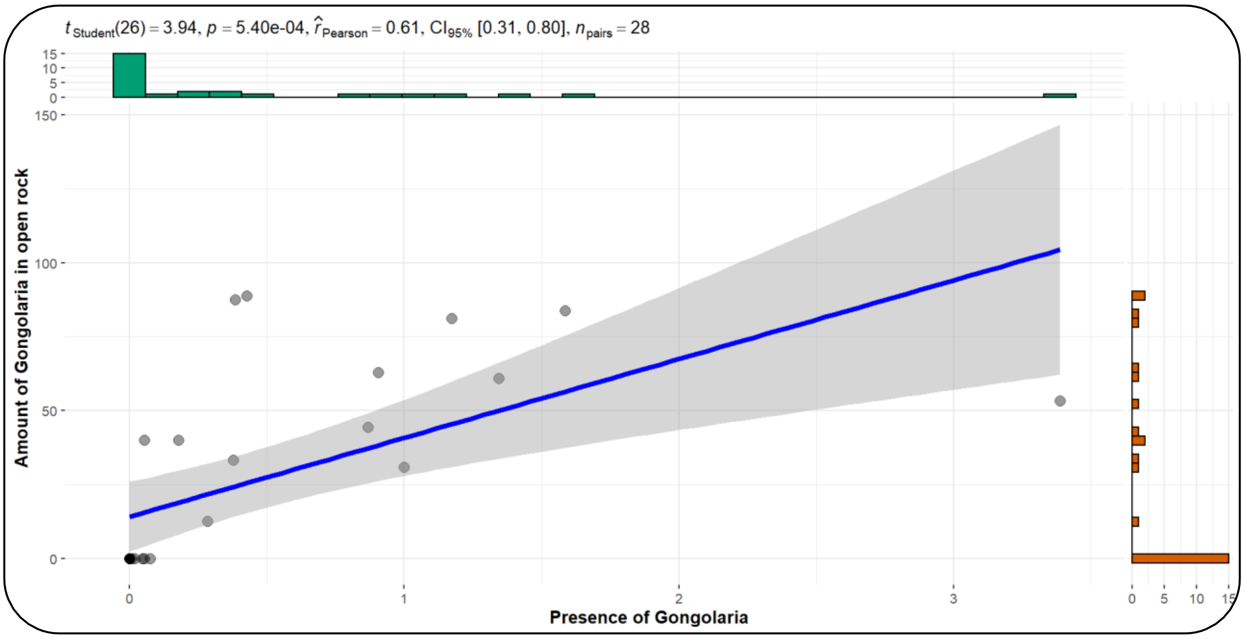

Figure 11. Relationship between the small-scale presence (e.g., in terms of small-scall cover) of Gongolaria in open rock and the large-scale presence of Gongolaria (Km of coastal perimeter occupied per cell) in 2022 across the island of GC.

The lines and polygons that we classified as "open rock" habitat, were found the most in the west and north sectors of the island, that "points" which are in a hidden habitat were found all around the island, but in the case of the west and north stations, the presence of "open rock" (lines and polygons) examples was higher that the presence of hidden "points"; on the contrary, at the east and south study stations the presence of "points" was high while the presence of lines and polygons was almost null. Talking about kind of habitat o presence of *Gongolaria abies - marina*, the 67,08% of the total presence of *G. abies - marina* in Gran Canaria is represented by hidden "points", while the 32,92 % left is represented by lines and polygons ("open rock habitats").

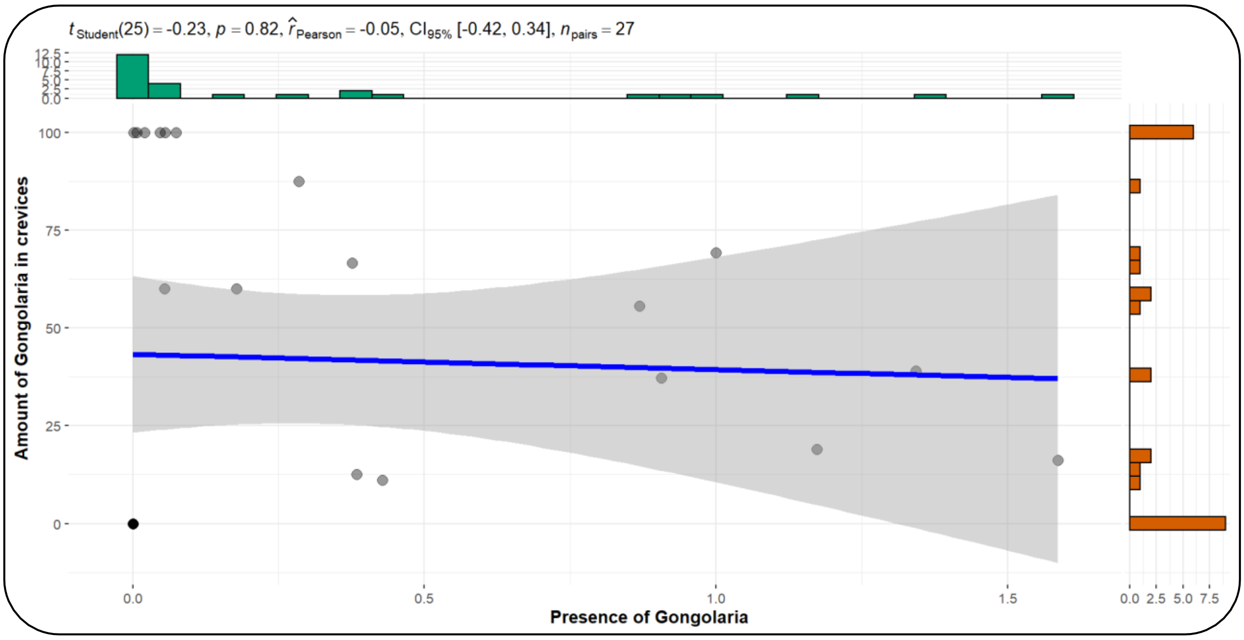

Figure 12. Relationship between the small-scale presence (e.g., in terms of small-scall cover) of Gongolaria in crevices and the large-scale presence of Gongolaria (Km of coastal perimeter occupied per cell) in 2022 across the island of GC.

Figure 13, represents the percentage of open rock and crevices habitat that we obtained during the study; as we commented before, we can see how in the east and south of the island the “crevices” habitats dominate, having high percentages of it and very low or null percentages of open rock habitats at these parts of the island; on the other hand, we can check that in the north and west coast of Gran Canaria, the examples of algae in crevices still be there, but the percentage of open rock *Gongolaria abies – marina* is in almost all the cells of north and west higher than the crevices habitat examples. We found the maximum values of crevices algae habitats on the sectors 2,6,7,8,10 and 13, where they dominate with a 100% of the presence; the maximum values of open rock habitats were found in the sectors 23 and 26, where the percentage of open rock *Gongolaria abies – marina* reached 88, 89 %.

In the figure can be seen some empty cells without any diagram inside, this is because in this study we did not find any evidence of *Gongolaria abies – marina.*

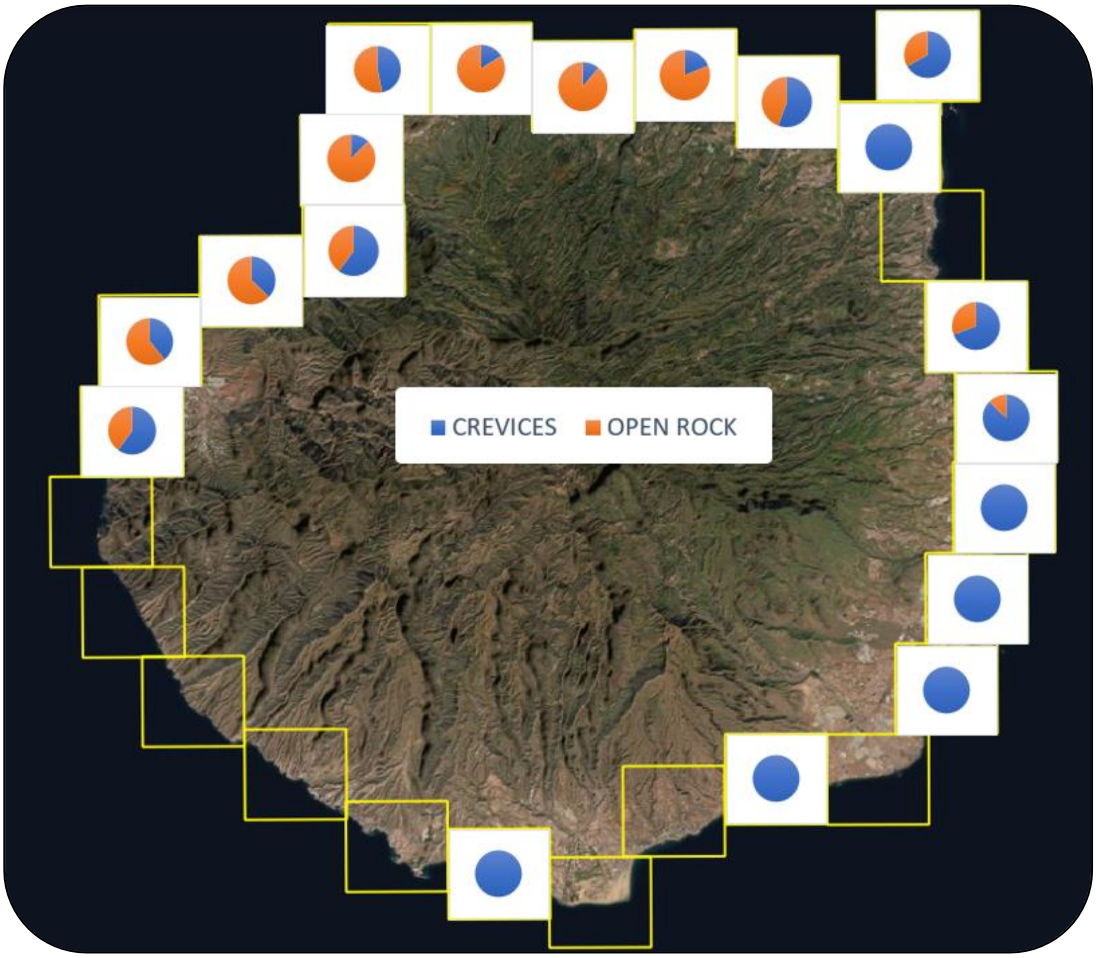

Figure 13. Percentages in the presence, in “crevices” or “open rock” in the small-scale presence of *Gongolaria abies – marina* in each cell.

In the table 1, we have the results of the multiple regression model to assess which environmental drivers better predicted the percentage of coverage at small scales (“open rock” and “crevices”). In table 1, we obtained the model as “open rock”, that states that the presence of *Gongolaria abies - marina* was particularly large in areas with a large wave power (Estimate=6,46; P=0,0003) while this same small scale presence of this algae was lowered in the sectors /cells with a large sea warming by considering the slope of SST through the last 40 years, having significance values (Estimate= -6,39; P= 0,01). As it can be seen in the Table 1, the “open rock” presence was large in cells where the large-scale presence of *Gongolaria - abies marina* was large (Estimate= 13,10; P=0,05). Overall, the small scale of *Gongolaria* in open rock was well explained by the set of modelled predictors variables with a total ca. 60% of explained variance (Table 1).

	Estimate	Std. Error	t value	Pr (|t|)
(Intercept)	32.688	32.184	1.016	0.319924
Wp	6.463	1.566	4.128	0.000381
Slope SST	-6.393	2.405	-2.658	0.013778
P Gongolaria	13.104	6.377	2.055	0.050910

Multiple R - squared	0.6506
Adjusted R - squared	0.6069

Table 1. Results of the stepwise multiple regression testing the effect of local (cell) wave power, the area of each cell, the HAPI index per cell, the slope of the linear adjustment of SST through the last 40 years for each cell, and the large-scale presence of *Gongolaria abies - marina* (Km of coastal perimeter) in each cell, over the small-scale presence of GAB in open rock.

On the other hand, Table 2 presents the model to assess environmental predictors of the small-scale presence of *Gongolaria abies - marina* in "crevices". In this case, the set of modelled predictors variables hardly explain the small-scale presence in crevices of this algae, with a total ca. 11,7 % of explained variance (Table 2). We can see some significance value in the slope of SST through the last 40 years though (Estimate=11,51; P=0,03) explaining this some variance, with a particular larger presence of *Gongolaria abies - marina* in crevices (ca. 100% of cover) in cells under SST warming.

	Estimate	Std. Error	t value	Pr (|t|)
(Intercept)	-130,326	65.818	-1.980	0.0603
Wp	-2.550	3.029	-0,842	0.4089
HAPI	-4.555	5.107	-0,892	0.3820
Area	3.750	2.218	1.691	0.1050
Slope SST	11.513	5.035	2.287	0.032
P Gongolaria	0.072	11.936	0.006	0.995

Multiple R - squared	0.2812
Adjusted R - squared	0.1178

Table 2. Results of the stepwise multiple regression testing the effect of local (cell) wave power, the area of each cell, the HAPI index per cell, the slope of the linear adjustment of SST through the last 40 years for each cell, and the large-scale presence of *Gongolaria abies - marina* (Km of coastal perimeter) in each cell, over the small-scale presence of GAB in crevices.

HAPI INDEX

The results obtained on the HAPI index were the expected, having pollution and coast perturbations and alterations all around the whole island but with some parts of it with higher levels than others though. As it can be seen in the graphic (figure 9), the sector or cells with the highest values of pollution, therefore, high values of HAPI index are those which have more anthropogenic pressure, having big parts of it cell respective areas urbanized and industrialized, specially at the coast, having the highest values the cells 2, 4 and 14.

As we can observe in the figure 9, the HAPI index values are more elevated in the east and south of the Gran Canaria Island than the rest of it (north and west), specially on the southeast, part of the island, which is the most touristic, for that, the south of the island is highly urbanized with hotels, apartments and more, all this to have a good touristic offer. Therefore, the sector 14, which has the highest HAPI index value, as we see, is in the south, in the middle of a pure and exclusive touristic zone.

SST SLOPE

In the table 3 we can observe the values of the SST slope in each sector of the island over the last 40 years, giving us information about what are the parts of the island which have suffering the warming of the waters caused by climate change. As we can observe, the north, northeast and east of the island are those parts that have experimented a rapid warming, especially the east, showing values of SST slope of 15 (16 at the Isleta in the northeast); in the other hand, the coldest part of the island these last years is the west, seeing the values of the SST slope, having numbers between 10 and 11.

Sector	SlopeSST	Sector	SlopeSST
1	16,34	15	12,57
2	15,34	16	11,9
3	14,73	17	11,51
4	15,43	18	10,93
5	15,28	19	10,46
6	15,27	20	11,68
7	15,45	21	10,62
8	15,26	22	11,79
9	15,58	23	13,95
10	15,1	24	15,35
11	14,4	25	15,26
12	14,55	26	14,2
13	14,2	27	14,34
14	13,04	28	14,7

Table 3. Results of the SST slope in each sector of the island in the last 40 years.

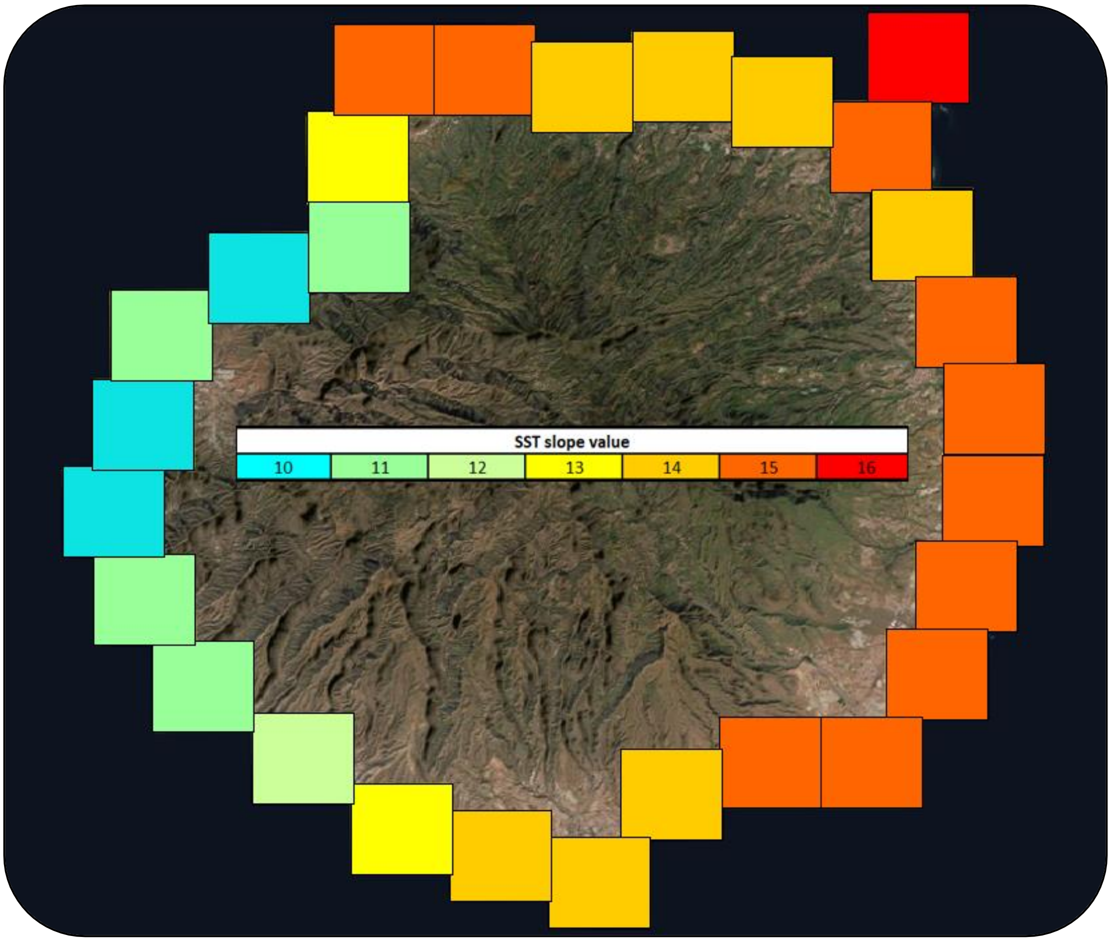

Figure 14. Gran Canaria map divided in 28 sectors with the SST slope of the past 40 years in each cell.

5. DISCUSSION

Currently, marine forests are in decline in many places worldwide, affecting the composition, structure, and biodiversity of benthic assemblages (Beck and Airoldi, 2007; Bernal-Ibanez *et al*., 2021b; Blanfuné *et al*., 2016; Filbee-Dexter and Scheibling, 2014; Thibaut *et al*., 2005; Bernal-Ibañez *et al.,* 2022). As we can observe in our results, the situation has not changed here; our data show that the percentage occupied by *Gongolaria abies - marina* on the coast of Gran Canaria has gone down respect 1987 and respect the last time *Gongolaria abies – marina* distribution was studied in this Gran Canaria Island by Valdazo *et al.,* (2017). Comparing with 2016, where the percentage of *G. abies - marina* occupied along the coast was 14,08% (37,8 km), in 2022, there is just a 4,04 % left (11,29 km). Similar to Valdazo *et al.,* (2017), we did not find a direct relation between the brown algae regression and the high levels of anthropogenic pressure on the island, but in the same way that these authors, we think that the pressure produced by the human could be a factor to keep in mind. However, we have found other environmental variables related to the regression, or limiting regression, of *Gongolaria abies – marina,* which were the wave power and the SST slope of the last 40 years. We observed that the northern and western sectors of the island are those that showed the greatest presence, at small scales, of the presence of *G. abies - marina* in "open rock" and, therefore, according to statistics, also at large – scales. These sectors are those with the highest average annual value of wave power, a variable that showed a positive effect on the presence of the species, particularly favoring a small-scale "open rock" distribution. Intense wave power allows the correct develop the alga, in addition to making the water cleaner and more oxygenated, possibly preventing the settlement of epiphytic algae and making the access to the alga difficult to herbivorous predators, like sea urchins or fishes like Salema (*Sarpa salpa*). Bernal-Ibañez *et al.,* (2022) reported, in another macaronesian island that an increase of a few degrees can significantly affect similar macroalgal species, being the temperature one of the main factors that drive their growth. This study agrees with these results, as our data showed a higher warming (in the last 40 years) in the northern, eastern, and southern sectors of Gran Canaria, areas where the presence of the algae, at small-scales, in "crevices" is notable, being able to demonstrate that they are areas where *Gongolaria abies – marina* seeks a refuge running away from this gradual rise in temperature. This affirmations match, at the same time, that of Perello *et al.,* (2021), who said that several years after heat waves, the brown algae specimens were only found in bottom refuges ("crevices" or cavities). Despite our results indicated that the small-scale presence in "crevices" is independent of the coastal perimeter (large – scale presence) occupied by the algae (i.e., around the entire island), it can be seen as in those areas mentioned before where the SST slope has large values, we found 100% algae in "crevices", in practically all the sectors, so we can suggest that the temperature has had a considerable influence on the distribution of *Gongolaria abies – marina* in Gran Canaria. It should be noted that, even though the northern sectors appear as areas with considerable warming, the presence on "open rock" is large, so, although the temperature has greatly influenced the populations along this part of the island, the presence of a high wave power allows this alga to continue its normal development. We can see to see this clear effect of temperature if we look at the sectors located a little further to the east, where the wave power intensity decreases and heating keep warming, resulting in a decrease of "open rock" presence, while the algae, seek protection in crevices.

Franco *et al.*, (2005) reported that the difference in the consumption of algae between open reefs and crevices is mediated by the local topographic features, which affect the heterogeneous spatial distribution of the marine algae (large-size brown algae). In their study, the distribution of marine algae inside the reefs showed a strong association with high complex structures (crevices) where the herbivory pressure was high. Similar to Franco *et al.*, (2005), our study indicates that the distribution of marine algae showed a strong association with high complex structures ("crevices") but in our case, we cannot relate these results with the high herbivory pressure, but we can do with, at least, with raising temperatures, seeing in our results, that large values of presence of *Gongolaria abies – marina* in "crevices", are significant influenced by the temperature, showing the small -scale presence in "crevices" a relation with high values of SST slope (Table 2). This is particularly acute in the intertidal, where our study focused, because it is subjected to large temperature fluctuations between tides.

The results of our study indicate a strong decline of the species *Gongolaria abies-marina* during the last years, with the current specimens (most of them) being found in crevices or cavities of the intertidal bottoms. This result agrees with those results obtained in the works of Franco *et al., (*2015) and Perello *et al.,* (2021), where they demonstrated the increasingly frequent presence of important macroalgae for ecosystems in shelters of high structural complexity such as crevices in the sea bottom. Perello *et al.*, (2021) also mentioned that the shelters of the seabed can simulate the understory ("Soto bosque"), promoting recruitment and survival of frondose macroalgae (Steneck *et al.,* 2002), so there are large possibilities that these crevices act as spore retainers, increasing the density and the chances of success of the specimens. If we compare our results with what was previously stated by these authors, they are in complete agreement, because the density of specimens of this brown alga in areas of high structural complexity were high, allowing us to demonstrate that in these kinds of habitats, the algae find a refuge to survive and develop.

Filbee *et al.,* (2020) said that kelp forest has declined in cover, biomass and in extent globally, and in many regions have been replaced by turf algae. Often, these declines and habitat transformations have been associated with increased sea temperatures at warm range edges. Analyzing this, our data can be related with these affirmations; although in our results we cannot confirm with total security that the changes in the distribution of *Gongolaria abies marina* occurred in Gran Canaria during the last 40 years are caused only because of the temperature increases. Filbee *et al.*, (2020) also showed that declines in sugar kelp (*Saccharina latissimi)* and shifts to structurally simplified turf seascapes over the last two decades in southern Norway and the eastern USA coincided with strong increases in the frequency and accumulative intensity of marine heat waves; lack of measures don't let them relate directly these marine heat waves and algae loss, but the data shows that marine heat waves can get the conditions of temperature beyond the limits of tolerance of the species.

Filbee and Wernberg, 2018 indicated that there is strong evidence that warming has played an important role in most shifts to turfs documented in the last decade. Ultimately, kelps are cool-water organisms, and, toward the warmer ends of their distribution, warming will reduce their growth, weaken their tissue, and negatively affect how they deal with other perturbations such as grazing, epiphytism, or mechanical damage (Wernberg *et al*., 2010, Simonson *et al*., 2015), saying as well it is clear that both periods of extreme warming and/or gradual increases in temperature are having increasingly severe direct or indirect effects on the reproduction, growth, and survival of kelps (Airoldi and Beck, 2007; Wernberg *et al*., 2010, Filbee-Dexter *et al*., 2016). Our results are in completely agree with these authors, showing our data that the variable which most significantly contributed to the decline of *Gongolaria abies – marina* was the temperature (SST slope), having become a long time ago an important problem for the survival and conservation of our oceans.

6. CONCLUSIONS

1. The decline of the brown algae species *Gongolaria abies marina* is a very urgent problem nowadays; the tendency from 1980`s keeps going down and, if the situation doesn´t change, *Gongolaria abies marina* will end disappearing.
2. In this study, we have found two environment factors that predict, better than others, the decline (or buffer the decay) of the brown algae *Gongolaria abies marina* during the last decades; wave power and the temperature, are the main environmental drivers on the distribution of the species across the island.
3. A high wave power naturally benefits the persistence of *Gongolaria abies – marina.* Even in areas under warming, the persistence of *G. abies – marina* is facilitated by high wave power.
4. Under a situation of progressive disappearance, hiding into "crevices" seems as a survival mechanism to guarantee survival.

7. REFERENCES

- Airoldi L., & Beck MW. (2007). Loss, status, and trends for coastal marine habitats of Europe. Oceanography Marine Biology Annual Review, 35: 345–405.
- Airoldi, L., Ballesteros, E., Buonuomo, *et al*. (2014). “Marine forests at risk: solutions to halt the loss and promote the recovery of Mediterranean canopy-forming seaweeds,” in The Proceedings of the 5th Mediterranean Symposium on Marine Vegetation, Portoroz, 28–33.
- Alfonso, B., Sansón, M., Sangil, C., Expósito, F., Díaz, J., & Hernández, J. (2022). Herbarium macroalgae specimens reveal a rapid reduction of thallus size and reproductive effort related with climate change. Marine Environmental Research, 174: 105-546.
- Arévalo, R., Pinedo, S., & Ballesteros, E. (2007). Changes in the composition and structure of Mediterranean rocky-shore communities following a gradient of nutrient enrichment: Descriptive study and test of proposed methods to assess water quality regarding macroalgae. Marine Pollution Bulletin, 55: 104–113.
- Ballesteros, E. (1989). Estructura y dinámica de la comunidad infralitoral de Codium vermilara (Olivi) Delle Chiaje de la Costa Brava (Mediterráneo Occidental). Anales de Biología, 15: 191-208.
- Ballesteros, E. (1992). Els vegetals i la zonació litoral: espècies, comunitats i factors que influeixen en la seva distribució. Secció de Ciències Biològiques, Institut d’Estudis Catalans, Barcelona.
- Barton, E.D., Arístegui, J., Tett, P. *et al.,* (1998). The transition zone of the Canary Current upwelling region. Progress in Oceanography, 41: 455-504.
- Bekkby T, Papadopoulou N, Fiorentino D. *et al.,* (2020). Habitat Features and Their Influence on the Restoration Potential of Marine Habitats in Europe. Frontiers in Marine Science, 7:184. doi: 10.3389/fmars.2020.00184.
- Belegratis, M. R., Bitis, I., Economou-Amilli, A., & Ott, J. A. (1999). Epiphytic patterns of macroalgal assemblages on Cystoseira species (Fucales, Phaeophyta) in the east coast of Attica (Aegean Sea, Greece). Hydrobiologia, 412: 67-80.
- Bellan-Santini, D., 1968. Influence de la pollution sur les peuplements benthiques. Revue Internationale d’Oceanographie Me´diterrane´enne, 10, 27–53.
- Bernal-Ibañez, A., Gestoso, I., Ramalhosa, P., & Campanati, C. (2022). Interaction of marine heat waves and grazing on two canopy-forming algae. Journal of Experimental Marine Biology and Ecology, 556 (2022) 151795.

- Benedetti-Cecchi L., Pannacciulli F., Bulleri F., et al. 2001. Predict- ing the consequences of anthropogenic disturbance: large-scale effects of loss of canopy algae on rocky shores. Marine Ecology Progress Series, 214: 137-150. https://doi.org/10.3354/meps214137
- Blanco, A. (2020). Cambios a medio término de las poblaciones de Cystoseira sensu lato (Fucales: Ochrophyta) en zonas resguardadas de Menorca. Trabajo de fin de Máster de la ULL, España.
- Borowitzka, M.A. (1972). Intertidal algal species diversity and the effect of pollution. Australian Journal of Marine and Freshwater Research, 23: 73–84.
- Boudouresque CF. Marine biodiversity in the Mediterranean: status of species, populations and communities. Scientific Reports of the Port-Cros National Park, 20:97–146.
- Burkepile DE, Hay ME. (2006) Herbivore vs. nutrient control of marine primary producers: context-dependent effects. Ecology, 87:3128–3139.
- Calumpong, H. P., and Fonseca, M. S. (2001). Seagrass transplantation and other seagrass. Global Seagrass Research Methods, 33:425. doi: 10.1016/B978-044450891-1/50023-2.
- Chapman, A. R. O. (1995). Functional ecology of fucoid algae: twenty-three years of progress. Phycologia, 34:1–32.
- Cheminée, A., Rider, M., Lenfant, *et al.*, (2017). Shallow rocky nursery habitat for fish: spatial variability of juvenile fishes among this poorly protected essential habitat. Marine Pollution Bulletin, 119(1): 245-254.
- Cheminée, A., Sala, E., Pastor, J., *et al.*, (2013). Nursery value of Cystoseira forests for Mediterranean rocky reef fishes. Journal of Experimental Marine Biology and Ecology, 442: 70–79.
- Christopher, D. G., Harley., Anderson K., *et al.*, (2012). Effects of climate change on global seaweed communities. Journal of Phycology, 48, 1064–1078 (2012) © 2012 Phycological Society of America DOI: 10.1111/j.1529-8817.2012.01224.x.
- Chung, I. K., Beardall, S., Mehta, D., *et al* (2011). Using marine macroalgae for carbon sequestration: a critical appraisal. Journal of Applied Phycology, 23:877–886.
- Creed, J.C., Kain, J.M. & Norton, T.A. (1998). An experimental evaluation of density and plant size in two large brown seaweeds. Journal of Phycology, 34: 39–52.
- Cuétara, M. (2020). Predicción de cambios en el fitobentos de las islas Canarias como consecuencia del calentamiento global. Trabajo fin de grado Universidad de La Laguna.
- Cyr H, Pace ML (1993) Magnitude and patterns of herbivory in aquatic and terrestrial ecosystems. Nature, 361:148–150.

- Davenport, N., Neuer, S., Helmke, P., *et al.*, (2002). Primary productivity in the northern Canary Islands region as inferred from SeaWiFS imagery. Deep Sea Research Part II: Topical Studies in Oceanography, 49: 3481-3496.
- De La Fuente, G., Chiantore, M., Asnaghi, V., *et al.*, (2019). First ex situ outplanting of the habitat-forming seaweed Cystoseira amentacea var. stricta from a restoration perspective, PeerJ 7:e7290. doi: 10.7717/peerj.7290
- Denman, K., Brasseur, A., Chidthaisong, *et al.*, (2007). Couplings between changes in the climate system and biogeochemistry. Pp. 541–584 in S. Solomon, D. Quin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, eds. Climate change 2007: the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K. and New York, NY
- Dijkstra, J. A., Boudreau, J., and Dionne, M. (2012). Speciesspecific mediation of temperature and community interactions by multiple foundation species, Oikos 121:646–654.
- Engelen, A.H., Aberg, P., Olsen, J.L., *et al.*, (2005). Effects of wave exposure and depth on biomass, density and fertility of the fucoid seaweed Sargassum polyceratium (Phaeophyta, Sargassaceae). European Journal of Phycology, 40: 149–158
- Falace, A., Kaleb, S., De La Fuente, G., Asnaghi, V., & Chiantore, M. (2018). Ex situ cultivation protocol for Cystoseira amentacea var. stricta (Fucales, Phaeophyceae) from a restoration perspective. PLoS ONE, 13(2): e0193011. https://doi.org/10.1371/journal.pone.0193011
- Filbee, K., & Wernberg, T. (2018). Rise of Turfs: A New Battlefront for Globally Declining Kelp Forest. BioScience, XX: 1–13.
- Filbee, K., Wernberg, T., Grace, S., *et al.*, (2020). Marine heatwaves and the collapse of marginal North Atlantic kelp forest. Scientific Reports, 10:13388.
- Filbee-Dexter, K., Feehan, CJ., Scheibling, RE. (2016). Large-scale degradation of a kelp ecosystem in an ocean warming hotspot. Marine Ecology Progress Series, 543: 141–152.
- Flechter, R. (1996). The occurrence of green tides. A review. In: Schramm, W., Nienhuis, P.H. (Eds.), Recent Changes and the Effects of Eutrophication, Ecological Studies, vol. 123, Marine Benthic Vegetation. Springer, pp. 7–30
- Gao, K., and K. McKinley. (1994). Use of macroalgae for marine biomass production and CO2 remediation: a review. Journal of Applied Phycology, 6: 45–60.
- García-Fernández A., Bárbara I. (2016). Studies of Cystoseira assemblages in Northern Atlantic Iberia. Anales del Jardín Botánico de Madrid, 73: e035.

- Geppi, B., & Riera, R. (2022). Responses of intertidal seaweeds to warming: A 38 – year time series shows difference of sizes. Estuarine, Coastal and Shelf Science, 270:107-841.
- Giaccone G., Alongi G., Pizzuto F., *et al*., (1994). La Vegetazione marina bentonica fotofila del Mediterraneo: 2: Infralitorale e Circalitorale: proposte di aggiornamento. The Bulletin of the Gioenia Academy of Natural Sciences Catania, 27(346): 111-157.
- Guern, M. (1962). Embryologie de quelques espéces du genre CystoseiraAgardh 1821 (Fucales). Vie et Milieu, 13: 649–679.
- Halpern B.S., Walbridge S., Selkoe K.A., *et al*., (2008). A global map of human impact on marine ecosystems. Science, 319(5865): 948-952. https://doi.org/10.1126/science.1149345
- Harley, C. D. G. (2011). Climate change, keystone predation, and biodiversity loss. Science, 334:1124–7.
- Haroun, R., Gil-Rodríguez, M., Díaz de Castro, J., & Prud´homme van Reine, W. (2002). A Checklist of the Marine Plants from the Canary Islands (Central Eastern Atlantic Ocean). Botanica Marina, Vol. 45, 2002, pp. 139±169
- Jones C.G., Lawton J.H., Shachak M. 1994. Organisms as ecosystem engineers. Oikos, 69: 373-386. https://doi.org/10.2307/3545850
- Ling S.D., Scheibling R.E., Rassweiler A., *et al*., (2015). Global regime shift of catastrophic sea urchin overgrazing. Philophical Transactions of the Royal Society B, 370: 20130269. https://doi.org/10.1098/rstb.2013.0269
- Littler, M.M., Murray, S.N., (1975). Impact of sewage on the distribution, abundance and community structure of rocky intertidal macroorganisms. Marine Biology 30, 277–291.
- Mangialajo, L., Chiantore, M., Susini, M-L, *et al.*, (2012). Zonation patterns and interspecific relationships of fucoids in microtidal environments. Journal of Experimental Marine Biology and Ecology, 412: 72–80.
- Marzinelli EM, Campbell AH, Vergés A, *et al., (*2014). Restoring seaweeds: does the declining fucoid Phyllospora comosa support different biodiversity than other habitats? Journal of Applied Phycology, 26(2):1089–1096. https://doi.org/10.1007/s10811-013-0158-5
- Medina, M. (1997). Estudio ecofisiológico de las praderas de Cystoseira abies-marina (S.G. Gmel.) C. Agardh en el Archipiélago Canario. PhD thesis, Tech. Univ. La Laguna, 155 pp
- Mineur, F., Arenas, F., Assis, J., *et al.*, (2015). European seaweeds under pressure: Consequences for communities and ecosystem functioning. Journal of Sea Research, 2015; 98:91–108.

- Montesanto, B., & Panayotidis, P. (2001). The Cystoseira spp. communities from the Aegean Sea (NE Mediterranean). Mediterranean Marine Science, 2(1): 57-68
- Morrison, D. (1988) Comparing fish and urchin grazing in shallow and deeper coral-reef algal communities. Ecology, 69: 1367–1382.
- Munda, I.M., (1974). Changes and succession in the benthic algal associations of slightly polluted habitats. Revue Internationale d'Oceanographie Mediterranenne, 34: 37–52.
- Munda IM. (1993). Changes and degradation of seaweed stands in the Northern Adriatic. Hydrobiologia, 1993; 260(1):239–253. https://doi.org/10.1007/BF00049025
- Muraoka, D. (2004). Seaweed resources as a source of carbon fixation. Bulletin of Fisheries Research Agency, (Suppl. 1):59–63.
- Oliveras M., Gómez A. (1989). Corología del género Cystoseira C. Agardh (Phaeophyceae, Fucales). Anales del Jardín Botánico de Madrid, 46: 89-97
- Pagès, J. F., Farina, S., Gera, A., *et al.*, (2012). Indirect interactions in seagrasses: fish herbivores increase predation risk to sea urchins by modifying plant traits. Functional Ecology, 26, 1015–1023. doi: 10.1111/j. 1365-2435.2012.02038.x
- Pardi, G., Piazzi, L., & Cinelli, F. (2000). Demographic study of a Cystoseira humilis Kützing (Fucales: Cystoseiraceae) population in the western mediterranean. Botanica Marina, 43(1): 81-86.
- Paulo, D., Cunha, AH., Boavida, J., *et al.*, (2019) Open Coast Seagrass Restoration. Can We Do It? Large Scale Seagrass Transplants. Frontiers in Marine Science, 6:52. doi: 10.3389/fmars.2019.00052
- Piazzi, L., & Ceccherelli, G. (2017). Concomitance of oligotrophy and low grazing pressure is essential for the resilience of Mediterranean subtidal forests. Marine Pollution Bulletin, 123: 197–204.
- Pinnegar, J. K., Polunin, N. V. C., Francour, P., *et al*., (2000). Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. Environmental Conservation, 27, 179–200. doi: 10.1017/S0376892900000205.
- Prud'homme van Reine, W. F. (1998). Seaweeds and biogeography in the Macaronesian Region. Boletim do Museu Municioal do Funchal, Supl. 5B: 307±331G
- Prud'homme van Reine, W. F. and C. van den Hoek. (1990). Biogeography of Macaronesian seaweeds. Courier Forschungsinstitut Senckenberg, 129: 55±73.
- Riera R., Sangil C., Sansón M. (2015). Long-term herbarium data reveal the decline of a temperate-water algae at its southern range. Estuarine, Coastal and Shelf Science, 165: 159-165. https://doi.org/10.1016/j.ecss.2015.05.008
- Sales, M., Cebrian, E., Tomas, F., Ballesteros, E. (2011). Pollution impacts and recovery potential in three species of the genus Cystoseira (Fucales, Heterokontophyta). Estuarine,

Coastal and Shelf Science, 2011; 92(3):347–357. https://doi.org/10.1016/j.ecss.2011.01.008

- Sales, M., & Ballesteros, E. (2007). Shallow, sheltered water populations of Cystoseira sp. in Menorca (Balearic Islands). Actes du 3eme Symposium méditerranéen sur la végétation marine, 164-171.
- Sales, M., & Ballesteros, E. (2009). Shallow Cystoseira (Fucales: Ochrophyta) assemblages thriving in sheltered areas from Menorca (NW Mediterranean): relationships with environmental factors and anthropogenic pressures. Estuarine, Coastal and Shelf Science, 84(4): 476-482
- Sales, M., & Ballesteros, E. (2012). Seasonal dynamics and annual production of Cystoseira crinita (Fucales: Ochrophyta)-dominated assemblages from the northwestern Mediterranean. Scientia Marina, 76(2): 391-401.
- Sales, M., Ballesteros, E., Anderson, M. J., *et al.*, (2012). Biogeographical patterns of algal communities in the Mediterranean Sea: Cystoseira crinita -dominated assemblages as a case study. Journal of Biogeography, 39(1): 140-152.
- Sansón M., Reyes J., Afonso-Carrillo J. (2001). Flora marina. In: Fernández Palacios J.M., Martín-Esquivel J.L. (eds). Naturaleza de las Islas Canarias: ecología y conservación, pp. 193-198.
- Sansón M., Sangil C., Orellana S., *et al.*, (2013). Do the size shifts of marine macroalgae match the warming trends in the Canary Islands? In: XIX Simposio de Botanica Criptogamica. Las Palmas de Gran Canaria, 24-28 June
- Silva, P. C. (1992). Geographic patterns of diversity in benthic marine algae. Pacific Science, 46: 429±437.
- Simonson, EJ., Metaxas, A., Scheibling, RE. (2015). Kelp in hot water: Effects of warming seawater temperature on kelp quality as a food source and settlement substrate. Marine Ecology Progress Series, 537: 105–119.
- Soltan, D., (2001). E´tude de l'incidence de rejets urbains sur les peuplements superficiels de macroalgues en Me´diterrane´e nord-occidentale. The`se Doctorat, Universite´ de la Me´diterrane´e-Centre d'Oce´anologie de Marseille, 157 pp
- Steneck, R.S., Graham, M.H., Bourque, B.J., *et al.*, (2002). Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental Conservation, 29: 436–459.
- Susini, ML., Mangialajo, L., Thibaut, T., Meinesz, A. (2007). Development of a transplantation technique of Cystoseira amentacea var. stricta and Cystoseira compressa. Hydrobiologia, 2007; 580(1):241–244. https:// doi.org/10.1007/s10750-006-0449-9
- Tuya F., Haroun R. (2006). Spatial patterns and response to wave exposure of photophilic algal assemblages across the Canarian Archipelago: a multi-scaled approach. Marine Ecology Progress Series, 311: 15-28.

- Tuya, F., Boyra, A., Sanchez, P., Barbera, C., & Haroun, R. (2004). Relationships between rocky-reef fish assemblages, the sea urchin Diadema antillarum and macroalgae throughout the Canarian Archipelago. Marine Ecology Progress Series, Vol. 278: 157–169, 2004.
- Tuya, F., Cacabelos, E., Duarte, P., *et al.*, (2012). Patterns of landscape and assemblage structure along a latitudinal gradient in ocean climate. Marine Ecology Progress Series, 466: 9–19.
- Valdazo, J., Viera, M., & Tuya, F. (2020). Seasonality in the canopy structure of the endangered brown macroalga Cystoseira abies-marina at Gran Canaria Island (Canary Islands, eastern Atlantic). European Journal of Phycology, VOL. 55, NO. 3, 253–265 https://doi.org/10.1080/09670262.2019.1696989.
- Valdazo, J., Viera, M., Espino, F., Haroun, R., & Tuya, F. (2017). Massive decline of Cystoseira abies-marina forests in Gran Canaria Island (Canary Islands, eastern Atlantic). Scientia Marina, 81(4): 499-507.
- Verdura, J., Vergés, A., Santamaria, J., *et al.*, (2018). Drastic effects of climate change on Mediterranean marine forest. PeerJ, 6: e26804v2.
- Vergés, A., Alcoverro, T., & Ballesteros, E. (2009). Role of fish herbivory in structuring the vertical distribution of canopy algae Cystoseira spp. in the Mediterranean Sea. Marine Ecology Progress Series, Vol. 375: 1–11, 2009.
- Wahl, M., Jormalaineny, V., Erikssonz, B.K. *et al*., (2011). Stress ecology in Fucus: abiotic, biotic and genetic interactions. Pp. 37–105 in M. Lesser, ed. Advances in Marine Biology. Academic Press, Oxford.
- Wernberg, T., Thomsen, MS., Tuya, F., *et al.*, (2010). Decreasing resilience of kelp beds along a latitudinal temperature gradient: Potential implications for a warmer future. Ecology Letters, 13: 685−694.
- Wildpret W., Gil-Rodríguez M.C., Afonso-Carrillo J. (1987). Cartografía de los campos de algas y praderas de fanerógamas marinas del piso infralitoral del Archipiélago Canario. Departamento de Botánica, Facultad de Biología, Universidad de La Laguna. Tomos I, II y III
- Wildpret, W., Gil-Rodríguez, M.C. & Afonso-Carrillo J. (1987). Cartografía de los campos de algas y praderas de fanerógamas marinas del piso infralitoral del Archipiélago Canario. Consejería de Agricultura y Pesca. Gobierno de Canarias, unpubl., Santa Cruz de Tenerife.
- Witman JD (1987) Subtidal coexistence—storms, grazing, mutualism, and the zonation of kelps and mussels. Ecological Monographs, 57:167–187

- Wootton, J. T., Pfister, C. A. & Forester, J. D. (2008). Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. Proceedings of the National Academy of Sciences, U.S.A, 105:18848–53.
- Zhang Q.S., Li W., Liu S., *et al*. (2009). Size-dependence of reproductive allocation of Sargassum thunbergii (Sargassaceae, Phaeophyta) in Bohai Bay, China. Aquat. Bot. 91: 194-198. https://doi.org/10.1016/j.aquabot.2009.06.003.