UNIVERSITY OF NOVA GORICA
SCHOOL OF ENVIRONMENTAL SCIENCES

DECLINE IN THE POPULATIONS OF *Fucus spiralis* L. PRESENT IN THE CANARY ISLANDS IN RELATION TO CLIMATE CHANGE

DIPLOMA THESIS

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DECLARATION

I declare that this graduate thesis is the result of my own research work. The results which are derived from joint research with other researchers or are contributed by other researchers (experts) are explicitly shown or listed (quoted) in the thesis.

Janez Vodopivec

ACKNOWLEDGEMENTS

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SUMMARY

Fucus spiralis L. (Phaeophyta) is one of the most common brown intertidal algae on the shores of the North Atlantic coast and it can be found in the North Pacific as well. Canarian populations represent the southernmost limit of the biogeographical distribution of these brown algae and a drastic decline of this fucoid has been observed in this area in recent decades. In the framework of a larger research program on climate change and marine biodiversity, the aim of this contribution is to assess the status of *F. spiralis* populations in Canary Islands and establish a link between the decline in its populations and global climate change. This would be achieved by comparing the results gathered in this study with historical distribution and morphological records on the species and connecting that to the data on environmental changes in the area which result from global climate change. Measurements of several biometric parameters have been done with monthly samples (from March 2010 to June 2010) of two different populations (Gàldar and Taliarte in Gran Canaria) and single episode samples (March 2010) from La Tejita in Tenerife, in order to evaluate morphological variation and its relationship with abiotic factors. Regarding the local distribution of *F. spiralis* in Canary Islands, a decrease of its extent was observed in both Tenerife and Gran Canaria, and the total disappearance of the following communities: Garachico, Caleta de Interián, Poris de Abona and Las Galletas in Tenerife and Agaete, Las Canteras and San Nicolas de Tolentino in Gran Canaria, most likely as a result of changes in abiotic factors. Morphometric results show the presence of the two *formae* (*F. spiralis* f. *limitaneus* and *F. spiralis* f. *platycarpus*) and there is evidence that the thalli in Gáldar (Gran Canaria) are on average bigger but less sexually developed (possess a lower number of receptacles per plant) compared to the thalli in Taliarte (Gran Canaria) and significantly bigger than the thalli from La Tejita (Tenerife), where the sexual development of the samples was not assessed. These differences could be consequences of the variety of environmental conditions that characterize individual sampling sites, but further studies are required in order to establish if the two *formae* represent an adaptive morphology to environmental conditions (ecotype) or if there is a seasonal pattern for what affects growth and reproduction.

KEY WORDS: Marine algae, *Fucus spiralis*, Canary Islands, distribution, morphology, climate change

POVZETEK

Fucus spiralis L. (Phaeophyta) je ena najpogostejših rjavih alg bibavičnega pasu na obalah severnega Atlantika, najdemo pa jo lahko tudi v severnem Pacifiku. Kanarski otoki predstavljajo najjužnejšo mejo biogeografske porazdelitve teh alg, v zadnjih desetletjih pa so na tem področju opazili drastičen upad njihovih populacij. V okviru širšega programa, ki raziskuje podnebne spremembe in biotsko raznovrstnost morja, je namen tega prispevka oceniti stanje populacij *F. spiralis* na Kanarskih otokih in vzpostaviti povezavo med upadom populacij in globalnimi klimatskimi spremembami. To bi bilo doseženo s primerjavo naših rezultatov z distribucijskimi in morfološkimi podatki o vrsti iz preteklosti in povezovanjem dobljenih ugotovitev s podatki o okoljskih spremembah na tem področju, kateri so posledica globalnih podnebnih sprememb. Meritve različnih biotskih parametrov so bile izvedene na mesečnih vzorcih (od marca 2010 do junija 2010) dveh različnih populacij (Gàldar in Taliarte z Gran Canarie) in enkratnih vzorcev (marec 2010) iz La Tejite na Tenerifu, z namenom oceniti morfološko raznolikost in njen odnos z abiotskimi dejavniki. V povezavi z lokalno distribucijo *F. spiralis* na Kanarskih otokih je bilo opaziti zmanjšanje njenega obsega tako na Tenerifu kot tudi Gran Canariji, in popolno izginotje naslednjih skupnosti: Garachico, Caleta de Interián, Poris de Abona in Las Galletas na Tenerifu in Agaete, Las Canteras in San Nicolas de Tolentino na Gran Canarii, najverjetneje kot posledica sprememb v abiotskih dejavnikih. Rezultati morfoloških meritev kažejo na prisotnost dveh oblik (*F. spiralis* f. *limitaneus* in *F. spiralis* f. *platycarpus*) in na to, da so vzorci iz Gáldar-ja (Gran Canaria) v povprečju večji, vendar manj spolno razviti kot vzorci iz Taliarte-a (Gran Canaria), oboji pa so bistveno večji kot vzorci iz La Tejite (Tenerife), kjer spolna razvitost vzorcev ni bila določena. Te razlike so lahko posledice različnih okoljskih dejavnikov, kateri opredeljujejo posamezna mesta vzorčenja, vendar so potrebne nadaljnje raziskave za ugotavljanje ali našteti dve obliki predstavljata morfološke odzive okoljskim pogojem (ekotip) ali če sezonski vzorci vplivajo na dejavnike, kateri narekujejo rast in razmnoževanje.

KLJUČNE BESEDE: Morske alge, *Fucus spiralis*, Kanarski otoki, distribucija, morfologija, podnebne spremembe

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1 INTRODUCTION

In recent decades, the effects of climate change are becoming an important area of interest in the decision making processes. In this sense, the presence, growth, reproduction and biomass of certain species of marine plants are also affected by the increase of seawater temperature and thus, different ecological parameters of benthic communities are likely to change (Niemeck & Mathieson, 1976).

Fucus spiralis L. a brown algae common on Atlantic coasts, is also present in Canary Islands, and forms small communities in the upper intertidal level (Reyes & Sansón, 1999). Nevertheless, these populations represent the southern limit of the biogeographical range of this brown algal species and in the last two decades, a drastic decline of the canarian populations of this fucoid has been observed. (R. Haroun, personal communication, 2010).

The objective of this research is to evaluate the local distribution and biological characteristics of the populations of *F. spiralis* in the Canary Islands, therefore various localities of *F. spiralis* from Gran Canaria and Tenerife were located and analyzed.

Samples were gathered from March 2010 until July 2010, thus collecting thalli from different stages of development. The laboratory analysis was focused mostly on the morphology of the species and the results gathered were later compared with existing records of *Fucus spiralis* populations in the Canary Islands.

In the framework of a larger research program on climate change and marine biodiversity (under the name “Ecological Status and Vulnerability of Canarian Marine Ecosystems to climate change: Evaluation of Biological and Ecological changes and Stress factors. ECOLIFE-ICA”), the aim of this contribution is to assess the status of *F. spiralis* populations in two Canarian Islands. The objective of this research is to evaluate the distribution and morphological variation of the different populations in the area.

By comparing the acquired results with existing data on the species distribution around the Canarian archipelago in the past, I hoped find a correlation between the changes in these populations and the changes in surface water temperature that result from global climate change.

2 THEORETICAL BASIS

2.1 *Fucus spiralis*

2.1.1. Description

Common names:
Spiral wrack (Dickinson, 1963)
Twisted wrack (no author reported)
Flat wrack (no author reported)
Jelly bags (no author reported)

Classification:
Empire Eukaryota
Kingdom Chromista
Subkingdom Chromobiota
Infrakingdom Heterokonta
Phylum Heterokontophyta
Class Phaeophyceae
Order Fucales
Family Fucaceae
Genus Fucus
Species *Fucus spiralis*

Publication details:
Fucus spiralis Linnaeus [Linnaeus, C. (1753). *Species plantarum*, exhibentes plantas rite cognitas, ad genera relatas, cum differentiis specificis, nominibus trivialibus, synonymis selectis, locis natalibus, secundum systema sexuale digestas. Vol. 2 pp. [i], 561-1200].

Type information:
Type locality: "in Oceano" [Atlantic Ocean] (Linnaeus 1753: 1159).
Lectotype: OXF Herb. Sherard (Powell 1960: 17).

The genus of Fucus belongs to the family Fucaceae, which currently includes 1038 species' (and intraspecific) names in the database at present, of which 13 are currently accepted taxonomically.

Homotypic Synonym:
Fucus sherardi f. *spiralis* (Linnaeus) Areschoug 1868
Heterotypic Synonyms:
-*Fucus vesiculosus* var. *spiralis* (Linnaeus) [C. Agardh 1810]
-*Fucus spiralis* var. *limitaneus* [Montagne 1856]
-*Fucus limitaneus* (Montagne) [Montagne 1856]
-*Fucus sherardi* f. *spiralis* (Linnaeus) [Areschoug 1868]
-*Fucus platycarpus* f. *nana* Schousboe [Bornet 1878]
-*Fucus spiralis* f. *borealis* [Kjellman 1883]
-*Fucus areschougii* [Kjellman 1890]
-*Fucus areschougii* f. *nanus* [Kjellman 1890]
-*Fucus areschougii* var. *borealis* (Kjellman) [Kjellman 1890]
-*Fucus spiralis* f. *nanus* (Kjellman) [Batters 1902]
-*Fucus spiralis* var. *nanus* (Stackhouse) [Batters 1902]

-*Fucus spiralis* var. *typicus* [Børgesen 1902]
-*Fucus platycarpus* var. *limitaneus* (Montagne) [Sauvageau 1909]
-*Fucus spiralis* var. *nanus* (Kjellman) [S.M. Baker & Bohling 1916]
-*Fucus spiralis* f. *limitaneus* (Montagne) [Børgesen 1926]
-*Fucus spiralis* var. *platycarpus* f. *limitaneus* (Montagne) [Miranda 1931]
-*Fucus spiralis* f. *arenicola* [Hamel 1939]

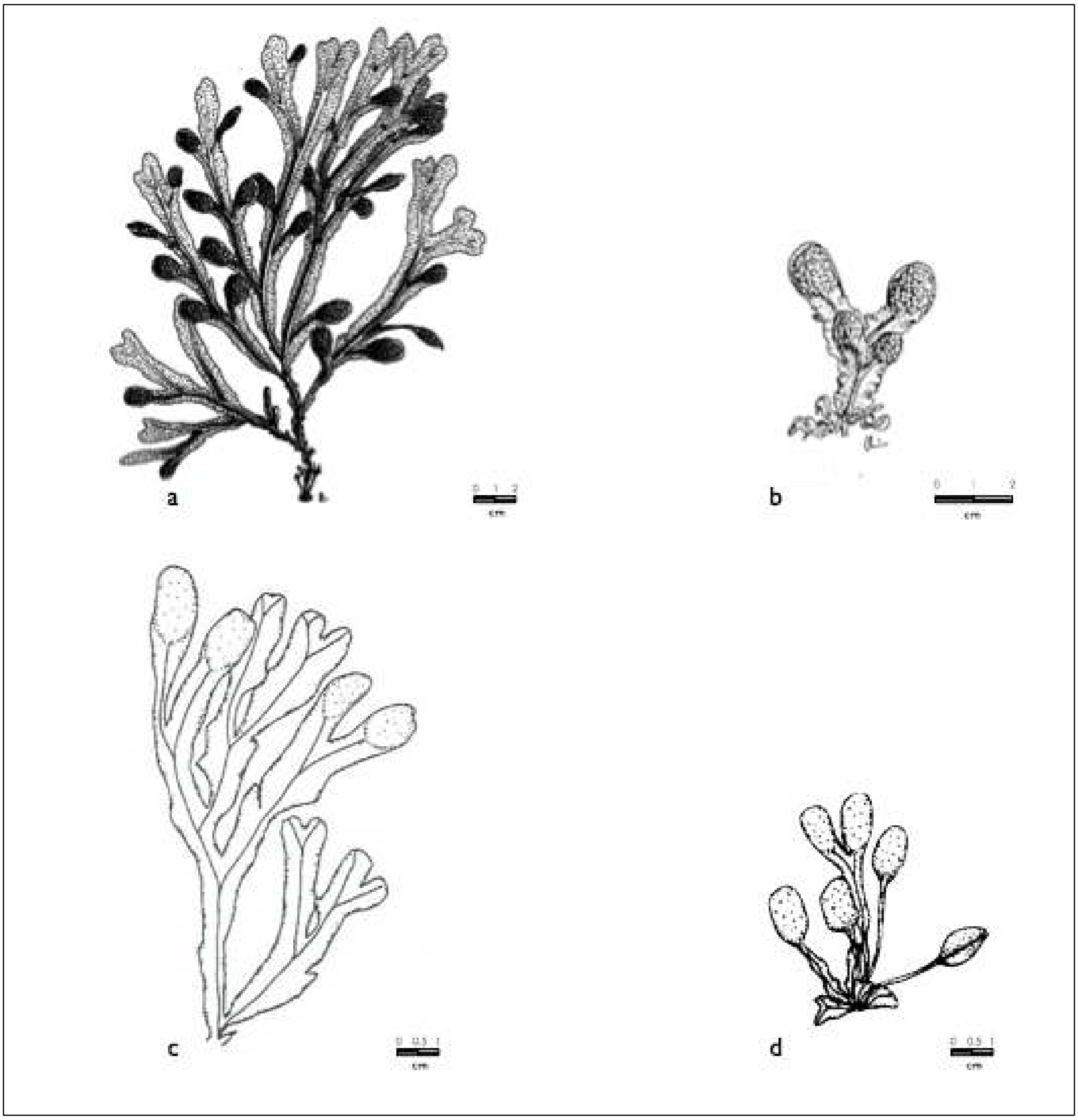

Figure 1: *Schemes of two forms of F. spiralis: a- Fucus spiralis var. platycarpus (from the Iberian peninsula; Gomez-Garreta et al., 2001); b- Fucus spiralis var. limitaneus (from the Iberian peninsula; Gomez-Garreta et al., 2001); c- Fucus spiralis var. platycarpus (from the Canary Islands; Reyes and Sansón, 1999); d- Fucus spiralis var. limitaneus (from the Canary Islands; Reyes and Sansón, 1999).*

General taxonomy:
Fucus spiralis is a species of seaweed, a brown alga, found in the intertidal zones on rocky shores of the Atlantic Ocean. These olive green colored plants can reach over 40 cm in length, are rather regularly branched and have dichotomies that are occasionally irregular (Niemeck & Mathieson, 1976). The branches that usually have a tendency to be erect, are mostly plane and occasionally somewhat twisted (hence the name *spiralis*). The spiraling of *F. spiralis* is most likely a consequence of the difference in water availability in the lower and upper part of the plant, which leads to different growth rates of the respective plant parts, leading to a spiral-like shape of the thalli (Burrows & Lodge, 1951). The branches are up to 15 mm wide, slightly ribbed below and near the base denuded to the midrib. The receptacles that appear at the ends of the branches can either be simply oval or sometimes forked, but they are always swollen.

Taxonomical notes:
As a general rule, members of the Fucales provide interesting examples of habitat linked morphological features which have caused and continue to cause a large measure of taxonomic confusion. This problem can be illustrated by the high number of species synonyms, *varietas* (= variety; a low-level taxonomic rank below that of species and signifies members of different populations that can interbreed easily, but not usually) and *formae* (= form; is a low-level taxonomic rank below that of variety) within the same species; as a final account also ecotypes (a genetically unique population that is adapted to its local environment) have been recorded for the species belonging to this family and for *Fucus spiralis* in particular (Russell, 1978), as stated by several authors that see the variable morphology as a direct consequence of different ecological features. In continental Spain, Gomez-Garreta *et al.* (2001) detected two varieties of *F. spiralis* (*F. spiralis* var. *limitaneus* and *F. spiralis* var. *platycarpus*). In the Canary Islands, Niell *et al.* (1987) and later Reyes and Sansón (1999) detected the same morphological differences, but stated it as two *formae.* Indeed the morphological data obtained from the canarian thalli are quite distinct from the samples of Gomez-Garreta *et al.* (2001), and according to the data obtained from the plants in continental Spain, there should be no *platycarpus* forms (or varieties) present in the Canaries, since the thalli are too small (usually less than 15 cm) or with a lower number of dichotomies (between 1 and 5). On the other hand it is clear that gross morphology shows high plasticity even in small thalli, so that it is possible to recognize the existence of two or more ecotypes (as shown by Niell *et al.* 1987).

Fucus spiralis var. *limitaneus*
In continental Spain Gomez-Garreta *et al.* (2001) described *F. spiralis* var. *limitaneus* as a small plant, 1-8 cm long when fertile, the frond between the holdfast and the first dichotomy is 1.2-2.2 mm wide and 0.5-2.3 cm long. Branching is simple, usually up to 3 dichotomies, with fronds reaching up to 11 mm wide. Receptacles are apical, 0.8-1.5 cm long and 0.8-1.2 cm wide, of simple spherical shape and surrounded by a sterile band with hermaphrodite conceptacles. This variety grows in the upper eulittoral zone, at the top of estuaries in areas less exposed to wave action.

Niell *et al.* (1987) described *F. spiralis* var. *limitaneus* in the Canary Islands as up to 6 cm long plants, which are very rarely branched (have a very low number of dichotomies). The average width of branches below the receptacles spans from 5 to 9 mm, the receptacles themselves are 8-15 mm long and 6-10 mm wide. As a general rule these plants display a very short axis, generally simple and linear (Reyes and Sansón, 1999).

Fucus spiralis var. *platycarpus*
In continental Spain the plant has been described by Gomez-Garreta *et al.* (2001) as 15-50 cm long when fertile, the frond between the holdfast and the first dichotomy is 1.5-4 mm wide and 1.2-6.5 cm long. Branching is dichotomous or pseudodichotomous (one of the branches interrupts its growth and develops a receptacle at the apex, which gives it a monopodial appearance). Fronds grow from 9-25 mm wide in the broader part. Receptacles are apical, 1-3.5 cm long and 1.3-2.6 cm wide, of round shape and surrounded by a sterile band with hermaphrodite conceptacles. This variety grows in the upper eulittoral zone, in places subject to moderate wave action.

Niell *et al.* (1987) described *F. spiralis* var. *platycarpus* in the Canary Islands as up to 15 cm long plants that develop up to 10 dichotomies. The branches below the receptacles are 8 to 14 mm wide, the receptacles themselves are 14-23 mm long and 8-14 mm wide. The plants belonging to this form have strong axis with a high number of dichotomies (Reyes and Sansón, 1999).

As a last observation, Reyes and Sansón (1999) also found that the populations of *F. spiralis* in Tenerife showed a crossing pattern from one form to another, depending on seasonal variation: in the autumn and winter seasons the plants exhibited more *limitaneus*-like features, whereas in spring and summer they resembled the *platycarpus* form, passing through an intermediate form, previously described by Niell *et al*. (1987).

Figure 2: *Registered herbarium sheet of the studied material (BCM herbarium – ULPGC).*

2.1.2 Life cycle

The specimens can live up to 4 years, with the average longevity between 2 and 2.5 years (Niemeck & Mathieson, 1976). It has a relatively simple life cycle and generates only one type of thallus. The species is hermaphrodite and has a monobiotic life cycle (Taylor, 1962). Fertilization is oogamous (Flora Phycologica Iberica. Vol.1. Fucales: pp.42-47), which is a form of sexual reproduction by gametes, where male and female gametes are morphologically very different. Male gamete, or sperm, is small and motile, whereas female gametes, or egg cells, are large and non-motile. They are formed in chambers called conceptacles, which group in fertile areas found at the tips of the branches of the sporophyte, called receptacles. The plants can be monoecious, where we can find the gametangia (oogonia and antheridia) in hermaphroditic or unisexual conceptacles, or dioecious. The attached oogonium is surrounded by a three layer wall, in which the meiotic division takes place. This is immediately followed by a mitotic division that results in eight eggs per oogonia. Antheridia, also attached at this stage, are surrounded by a two layer wall in which one meiotic division is followed by a number of mitotic divisions producing 64 sperm. Eventually the antheridia and oogonia are released into the water, where the eggs are fertilized, forming a zygote that develops directly into a diploid plant (Textbook of Algae: pp.300-304).

2.2 Geographic distribution

2.2.1 Global distribution

Previous studies have reported populations of *Fucus spiralis* as follows:

Ireland: Antrim (Guiry 1978, Morton 1994), Clare (Guiry 1978, De Valéra & Cooke 1979), Cork (Renouf 1931, Cullinane 1971, Cullinane, McCarthy & Fletcher 1975, Guiry 1978), Derry (Guiry 1978, Morton 1994), Donegal (Guiry 1978, Morton 2003), Down (Morton 1974, Hazlett & Seed 1976, Guiry 1978, Morton 1994), Dublin (Guiry 1978), Galway (Guiry 1978), Kerry (Guiry 1978), Louth (Synnott 1969, Guiry 1978), Mayo (Cotton 1912, Guiry 1978), Waterford (Guiry 1977, Guiry 1978), Wexford (Tighe 1803, Cotton 1913, Parkes & Scannell 1969, Norton 1970, Guiry 1978).
Europe: Baltic Sea (Nielsen *et al*. 1995), Belgium (Coppejans 1995), Britain (Newton 1931, Hardy & Guiry 2003, Perrin *et al*. 2007), Faroes (Irvine 1982, Nielsen & Gunnarsson 2001), France (Feldmann 1954, Coppejans 1995, Billard *et al*. 2005, Billard *et al.* 2006, Cerantola *et al* 2006, Dizerbo & Herpe 2007, Loiseaux-de Goër & Noailles 2008), Helgoland (Bartsch & Kuhlenkamp 2000), Ireland (Cotton 1912, Cotton 1913, Cullinane 1971, Guiry 1977, Guiry 1978, De Valéra *et al*. 1979, Morton 1994), Netherlands (Stegenga & Mol 1983), Norway (Rueness 1997), Portugal (De Mesquita Rodrigues 1963, Ardré 1970, Billard *et al.* 2006, Perrin *et al*. 2007, Araujo *et al*. 2009, Araújo, Bárbara & Sousa-Pinto in press), Scandinavia (Athanasiadis 1996), Spain (Lázaro Ibiza 1889, Sauvageau 1897, Sauvageau 1913, Hamel & Feldmann 1928, Hamel 1928, Miranda 1931, Fischer-Piette 1955, Seoane-Camba 1957, Ardré 1957, Fischer-Piette 1959, Fischer-Piette, C. & Seoane Camba, J. (1962), Seoane-Camba 1965, Pérez-Cirera & Maldonado 1982, Conde & Seoane 1982, Fernández & Niell 1982, Anadón 1983, Gallardo *et al*. 1985, Pérez-Cirera 1989, Ribera *et al*. 1992, Granja, Cremades & Barbara 1992, Flores-Moya *et al*. 1995, Bárbara & Cremades 1996, Veiga, Cremades & Bárbara 1998, Calvo, Bárbara & Cremades 1999, Veiga Villar 1999, Calvo & Bárbara 2002, Peña & Bárbara 2002, Gorostiaga *et al*., 2004, Bárbara *et al*. 2005, Lobón *et al*. 2008, de los Santos, Pérez-Lloréns & Vergara 2009), Sweden (Kylin 1947).
Europe (cited with different name than *Fucus spiralis*):
Ireland: Wexford (Tighe 1803), Ireland (Tighe 1803).
(as *Fucus vesiculosus* var. *spiralis* (Linnaeus) C.Agardh)
Scandinavia: (Athanasiadis 1996).
(as *Fucus spiralis* f. *borealis* Kjellman)
Sweden (Kylin 1907).
(as *Fucus areschougii* Kjellman)
Britain (Newton 1931), Ireland (Cotton 1912, Morton 1994).
(as *Fucus spiralis* var. *nanus* (Kjellman) S.M.Baker & Bohling)
Portugal (De Mesquita Rodrigues 1963), Spain (Sauvageau 1897, Miranda 1931, Seoane-Camba 1965, Flores-Moya et al. 1995, Gorostiaga *et al.*, 2004).
(as *Fucus spiralis* f. *limitaneus* (Montagne) Børgesen)
Spain (Miranda 1931).
(as *Fucus spiralis* var. *[platycarpus]* f. *limitaneus* (Montagne) Miranda)

Atlantic islands: Azores (Neto 1994, Tittley & Neto 1994), Canary Islands (Price, John & Lawson 1978, Gil-Rodríguez & Afonso-Carrillo 1980, Viera-Rodriguez *et al*. 1985, Campos *et al*. 1987, Alfonso-Carrillo *et al*. 1988, Guadalupe *et al*. 1995, Reyes & Sansón 1999, Haroun *et al.* 2002, Gil-Rodríguez *et al*. 2003, John *et al.* 2004).

Atlantic islands (cited with different name than *Fucus spiralis*):

Canary Islands (Børgesen 1926, Price, John & Lawson 1978).
(as *Fucus spiralis* f. *limitaneus* (Montagne) Børgesen)

North America[1]: Alaska (Lindstrom 1977, Scagel *et al*. 1989), British Columbia (Scagel *et al*. 1989), Connecticut (Van Patten 2006), Maine (Mathieson *et al.* 2001, Wallace *et al*. 2004, Coleman & Brawley 2005, Mathieson *et al.* 2006), Massachusetts (Mathieson *et al.* 2006), New Hampshire (Mathieson & Hehre 1986, Mathieson & Dawes 2002, Wallace *et al*. 2004), New York (Taylor 1957), Newfoundland (Taylor 1957), Quebec (Taylor 1957), Washington (Scagel *et al*. 1989), Anacortes, Washington (Coyer *et al*., 2006)

North America (cited with different name than *Fucus spiralis*):
Rhode Island (Taylor 1957).
(as *Fucus spiralis* var. *limitaneus* Montagne)

Africa: Morocco (Dangeard 1949, Gil-Rodriguez & Socorro Hernández 1986, Ribera *et al.* 1992).

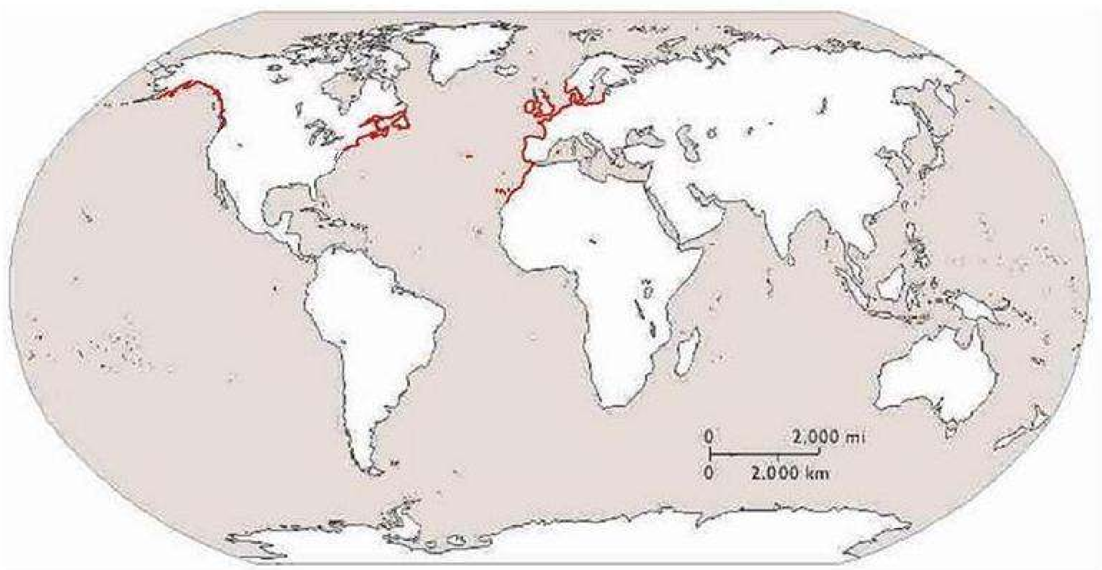

Figure 3: *Recorded global distribution of Fucus spiralis*

From these studies we can conclude that *Fucus spiralis* is fairly abundant on both sides of the Atlantic Ocean and it has been registered on the eastern Pacific coast of North America as well, from about 20º to about 60º north latitude. In Europe *Fucus spiralis* spreads from the Arctic Circle to the coasts of Morocco and the Canary Islands, which seem to be the southernmost limit of its populations. The distribution is most likely limited by surface water temperature which is too high to facilitate the species closer to the equator or too cold further up north.

[1] The presence of *F. Spiralis* in this area is unusual, since there is no trace of migration to the Pacific Ocean.

2.2.2 Local distribution on the coasts of Canary Islands and mapping

The analysis of material revised in the available literature allowed for the development of location tables and maps of natural populations of *F. spiralis* recorded in the Canary Islands.

In Table A.1 in the Annexes, the distribution of *F. spiralis* in the Canary Islands is presented, first in geographical and then chronological order. Enclosed therewith are the bibliographic reference, the sampling date, location, sexual phase and where the data was available, the littoral level and type of coastal substrate where the specimens were found.

Table A.2 of the Annexes lists the existing herbarium records of *F. spiralis* from the Herbarium BCM (Herbarium of the University of Las Palmas, Gran Canaria), Herbarium TFC (Herbarium of the University of La Laguna, Tenerife) and UMAL (Herbarium of the University of Maine, Maine, USA).

In pictures 4 and 5 below, the summaries of the bibliographic references and herbarium sheets are presented, respectively. The bibliographic references are specified by the authors and years of the corresponding publications (the authors in light color did not specify the exact location where the samples were found), whereas the herbarium records are accompanied by the names of their finders and the herbarium in which a detailed description can be found.

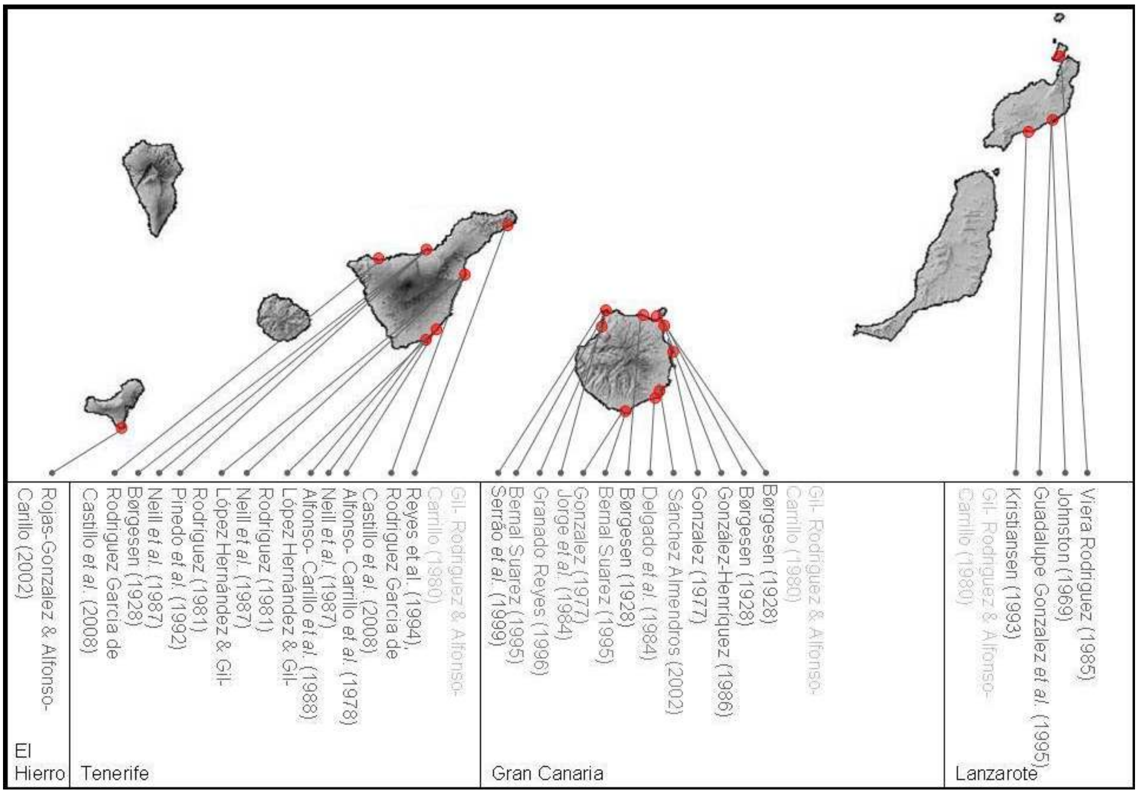

Figure 4: *Bibliographic records of F. spiralis within the Canarian archipelago*

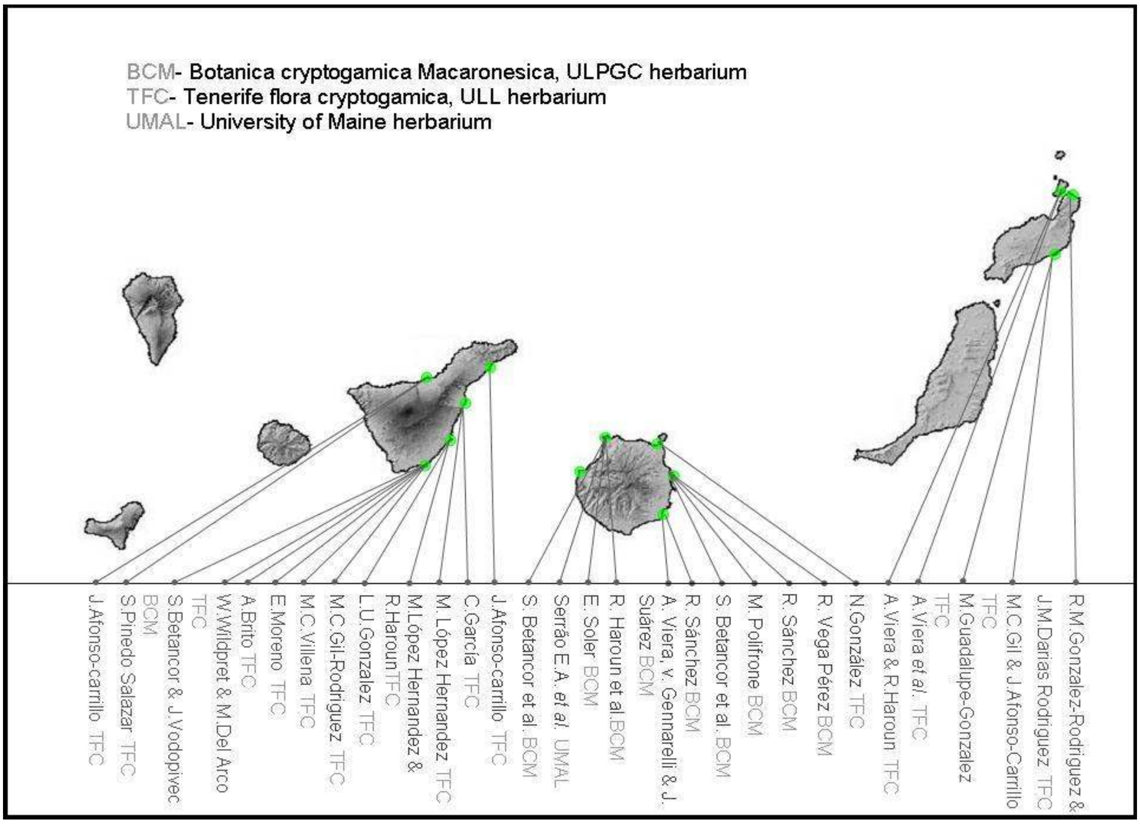

Figure 5: *Herbarium records of F. spiralis gathered from the Canarian archipelago*

2.3 Ecology and microdistribution

F. spiralis is a eurythermal and euryhaline species, accruing within a surface water temperature range of -0.5ºC to 23.1ºC and a salinity of 30‰- 32‰ (Niemeck & Mathieson, 1976).

The variability of oceanographic conditions on the Canarian shores (Barton *et al.*, 2000) offers the possibility for the development of benthic species with different distribution ranges, ranging from those with more temperate affinities to others more tropical (Haroun *et al.*, 2002). It is presumed that these vegetal benthic communities play an important role in coastal food chains and can also be used as bioindicators of the environmental quality of the shoreline (Pérez *et al.*, 2000). That is why much research has been done in the last decades with different species in order to gain more knowledge about how these complex communities interact with their environment.

According to Haroun and Alfonso-Carrillo (1996) it is possible to recognize over 600 species of macroalgae along with three species of marine flowering plants in the Canarian archipelago. As mentioned, the diversity of macroalgae present there consists of species with a very wide range of distribution, but a clear predominance of red algae can be observed, due to the proximity of the tropics (Feldmann, 1937). According to Feldmann (1937), the R/P index for the Canary archipelago is 385/125, which equals 3.08 which is characteristic of warm, temperate regions. Given their geographic location the islands are, in addition to the cold Canary current (a descending branch of the Gulf Stream), affected by cold-water upwelling from the nearby African coast (Barton *et al.*, 2000). Because of these factors it is possible to observe a sharp gradient of surface water temperature from the most eastern islands to the most westerly islands, the latter with more oceanic characteristics.

Zonation patterns
In the Canaries the tidal oscillation reaches up to about 3 m in height, but it can affect quite a variable area, depending on the inclination of the coast. Along rocky coasts the benthic organisms are usually spread in horizontal bands. The vertical distribution i.e. zonation, is present in coasts all over the world and includes algae as well as sessile animals and lichens. The registered number of species present defines these zones and can be used as a basis for characterization of different coastlines. The littoral zone is the part of a coast with organisms adapted to withstand immersion or unimmersion or tolerate spray (Lewis, 1964). The upper limit of the zone is marked by the disappearing of marine organisms. In the Canary Islands the littoral zone usually falls between the populations of the cirriped *Chthamallus stellanus* Poli on top, and *Cystoseira abies*- marina at the lower limit (Viera- Rodriguez & Wildpret, 1986).

Fucus spiralis occupies the top level of the intertidal zone in coasts of Europe (Borgesen, 1926; Luning, 1990). It can be found in sheltered sites as well as more exposed locations, where it is subjected to more extreme variations of atmospheric conditions. *Fucus spiralis* is restricted to metasedimentary or metavulcanic rock formations, which have a coarse structure with lots of cracks and fissures that probably offer some degree of protection for developing zygotes as well as adult plants (Lewis, 1972) and make their attachment to the surface easier and more firm.

The zone occupied by *Fucus spiralis* lies between 2.1 m and 2.3 m above the average low tide value (Niemeck & Mathieson, 1976) and within this zone it shows a microstratification of biomass, length of plants and reproductive activity, showing a decrease of these parameters with increasing elevation. Below the zone of *Fucus spiralis* there is a transition to *Fucus vesiculosus* and in between the zones a variety of Fucus can be found, sometimes difficult to identify, perhaps due to hybridization as suggested by Niemeck and Mathieson (1976). As mentioned in the description, apart from the substrate, two crucial factors limiting the distribution of *Fucus spiralis* are surface water temperature and salinity. Munda (1964, 1967) suggested that reduced salinity can accelerate the rate of fructification. Burrows and Lodge (1951) found that if the fructification of *Fucus spiralis* is accelerated it can result in overlapping with the fruiting of *Fucus vesiculosus*, which results in higher numbers of hybrids. Nutrients such as carbohydrates, phosphorous and nitrogenous substances seem to play a vital role in the initiation of reproduction, as some species of Fucus mature earlier near river discharges, which presumably enrich the ocean water with nutrients (Knight and Parke, 1950). Naylor (1956) suggested that photoperiod could also play a major role in the life-cycle of *Fucus spiralis*, because he had noticed some very odd latitudinal variations between the populations.

2.4 Changes in the ocean

According to Kamenos (2010) the measurements and modeling show that Atlantic marine temperatures are raising; however, the low temporal resolution of models and restricted spatial resolution of measurements firstly mask regional details critical for determining the rate and extent of climate variability, as well as prevent robust determination of climatic impacts on marine ecosystems.

The report on climate change in the Canary Islands prepared by the National Meteorological Agency (Agencia Estatal de Meteorología- AEMET) from April 2008, states that, according to the information provided by researchers from the Faculty of Marine Sciences at the University of Las Palmas de Gran Canaria, which is constantly monitoring the ocean in the north of the Canaries, mean surface seawater temperatures there have risen by about 1°C since 1985. The trends calculated based on the NCEP reanalysis (National Centers for Environmental Prediction, USA) confirmed the increase as well. Since 1948, the year from which onward the oceanographic data has been gathered by the NCEP, surface water temperature changes have had two distinct periods; a first period of decline until the mid-1970s, and a second period of fast rising since then (Picture 6). This behavior is similar to that in other environments and it simply reflects the behavior of mean global air temperatures. Trends calculated over short periods of time show increases and decreases, while over long periods show that the temperature rising overcompensates for the cooling, and the overall effect is warming. In some years, like 1999, there were very significant cold anomalies and thermal growth seemed to stop, but in 2003 and 2004 significant warm anomalies occurred, again confirming the overall warming trend.

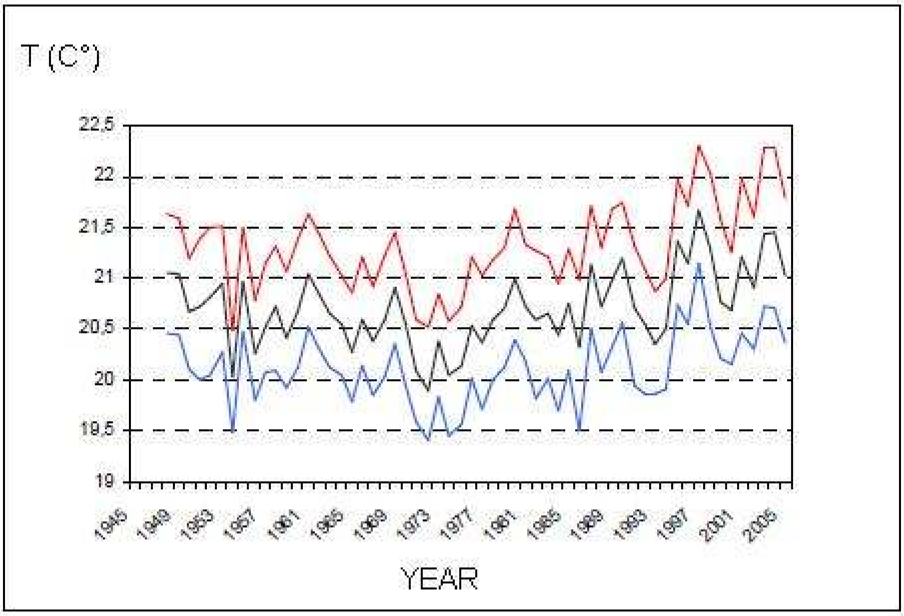

Figure 6: *Mean surface seawater temperature fluctuations since 1948. Red line represents mean T at La Restinga (El Hierro) on the South West of the archipelago; Black line represents mean T for the whole Canarian sea; Blue line represents the mean T at La Graciosa on the North East of the archipelago. (Source: Hernández, 2008: 14)*

In the seventies the average surface water temperature was 20.33ºC, while in the phase of progressive increase in recent decades reached 21.11°C, with the maximum value in 1997 (21.66°C) and a number of years later also very warm in 2003 and 2004. Therefore, the trend is clearly increasing, although the process is not uniform and there are alternating colder and warmer years and occasional intense phenomena such as overheating in the summer of 2004 when highest water temperatures in history were recorded around the islands, reaching 27º -28ºC in July and August, so the area almost reached the tropical thermal front. Undoubtedly, this surface effect must have had a response in mid-water layers and to a lesser extent in the deep as well, but there is a lack of data to support this. Unfortunately, many of the systems monitoring the parameters of the Canarian sea conditions did not begin to operate until the nineties, well inside the period of heavy global warming, thus leaving us with insufficient data for comparison.

The report on climate change in the Canary Islands prepared by AEMET in April 2008 notes that, according to the data from various tide gauges in marine ports and the IGN (Instituto Geográfico Nacional- National Geographic Institute), the average sea level is rising in the Islands at a rate of 0.8 mm / year, similar to that recorded in the Strait of Gibraltar but significantly lower than that in the Bay of Biscay (2.5 mm / year).

According to A. B. Hernández (2008) an increase of seawater-dissolved carbon dioxide has been observed since 1997, as well as an increase in water acidification which is lowering the pH level at a rate of 0.002 units per year since then.

3 MATERIALS AND METHODS

The nature of this study has led to the consideration of multiple parameters in order to achieve the objectives set, both in determining the distribution and morphological features of *Fucus spiralis* in the Canary Islands, as well as its response to rising seawater temperatures. The following chapter describes the sampling design and methodology used in each phase of this experimental work.

3.1 Methodology

Monthly samples were collected in the intertidal and subtidal zones of selected sampling stations along the coasts of Gran Canaria and Tenerife. All the samples have been thoroughly analyzed in the laboratory, focusing on their morphology in different life stages. After the field and laboratory work had been finished, the data obtained was compared with existing data extracted from previous studies of similar or same benthic communities to evaluate potential changes related to seawater temperature fluctuations. As these fluctuations are consequences of a slowly developing process, the data could not be obtained by monitoring the seawater temperatures, but rather by reviewing what had already been written about the subject.

3.2 Sampling design

Prior to any sampling campaign, a previous study (Reyes & Sansón, 1999) was consulted to determine where exactly the sampling will take place, as this is the most recent study of this sort and therefore most appropriate as a template when assessing the changes in populations in recent years. In addition, other related research, as well as mapped reference material deposited in the herbarium of the University of Las Palmas and the University of La Laguna has been consulted, in order to have all the possible information on the species' distribution in the past.

For determining the distribution, XY coordinates of the colonies observed were marked with a GPS apparatus (Garmin GPSMAP ®-276C). With this information acquired, past and present distribution maps were created using a blank map of the Canarian archipelago. The sampling campaign was conducted between March 2010 and July 2010, covering the areas where *F. spiralis* had been recorded by Reyes & Sansón (1999), in the islands of Gran Canaria and Tenerife (unfortunatly circumstances did not allow conducting of the sampling on other Canarian islands as well). Since *Fucus spiralis* is an intertidal species it was only possible to conduct the sampling during the best tidal and weather conditions (lowest tide levels, small waves), which was approximately once a month in Gran Canaria, and just once overall in Tenerife.

The encountered localities were first visually inspected to determine if they were strong enough to be sampled i.e. had a high enough number of individuals so that the sampling did not damage the colony. Samples were than taken randomly by hand from the suitable colonies, with the number of individual thali taken depending on the size of the population (ranging from 5 for small, to 15 samples for bigger colonies). Sampling sites were also measured and photographed for future reference. The gathered samples were stored in closed plastic bags within a few minutes after picking, after that they were transported to the laboratory in styrofoam containers and stored in the refrigerator until further analysis (not more than 24 hours).

3.3 Morphology measuring

Before the morphological features of *F. spiralis* were measured, the article of Reyes & Sansón (1999) had again been consulted, so that the measured parameters would be as comparable as possible between the two studies. This would provide a clearer picture of the potential changes that might have taken place in the last two decades.

Following Reyes & Sansón (1999), all the samples from Gran Canaria were analyzed fresh (within 24 hours after collection). In the laboratory the samples were taken out of the plastic bags, dried off with a paper towel, the dichotomies and receptacles were counted and finally all the samples were scanned using a Hewlett Packard Scanjet 5500c scanner. Along with the plants I included a small piece of millimetre paper that provided the scale for easier, quicker and more precise measuring later on.

The samples from Tenerife were analyzed dry since the sampling campaign lasted for two days because of commuting reasons, and there was no way the morphological measurements could be conducted within the desired 24 hours. Consequently fresh samples were pressed between two pieces of paper using a simple wooden press, which allowed them to dry without affecting their shape. The newspapers were changed frequently to avoid the accumulation of mildew. After they had been scanned, the same process was performed on the samples from Gran Canaria as well, but only for the purpose of making herbarium sheets for the University's records.

The scanned images of the plants along with the millimeter paper were then ready for further analysis. For practical reasons the actual measurements were carried out using the ImageJ© 1.40g (Abramoff *et al.,* 2004) software, which allowed for quick and accurate measuring of the selected sample properties. This program includes tools used to determine lengths, angles and areas as well as other useful tools for computerized morphology measuring. Spatial calibration allows for real measurements and the results can be printed and exported to text files or spreadsheets for Microsoft®Excel® or SPSS©.

Measured parameters
As mentioned the measured parameters were selected according to the study of Reyes & Sansón (1999) in order to make the extent of changes in recent years easier to evaluate in the latter segments of this research. Thus the following properties were analyzed:
a- Maximal length- the longest distance measured vertically starting at the holdfast.
b- Maximal width- the longest distance measured horizontally starting at the far left side of the sample.
c- Proximal width- the width of the sample measured directly above the holdfast.
d- Medial width- the width of the sample measured at the first branching.
e- Branch width- the width of individual branches measured just below the receptacles.
f- Dichotomies- number of individual branchings within a single sample, counted by hand.
g- Receptacle length- average length of receptacles in a single sample.
h- Receptacle width- average width of receptacles in a single sample.

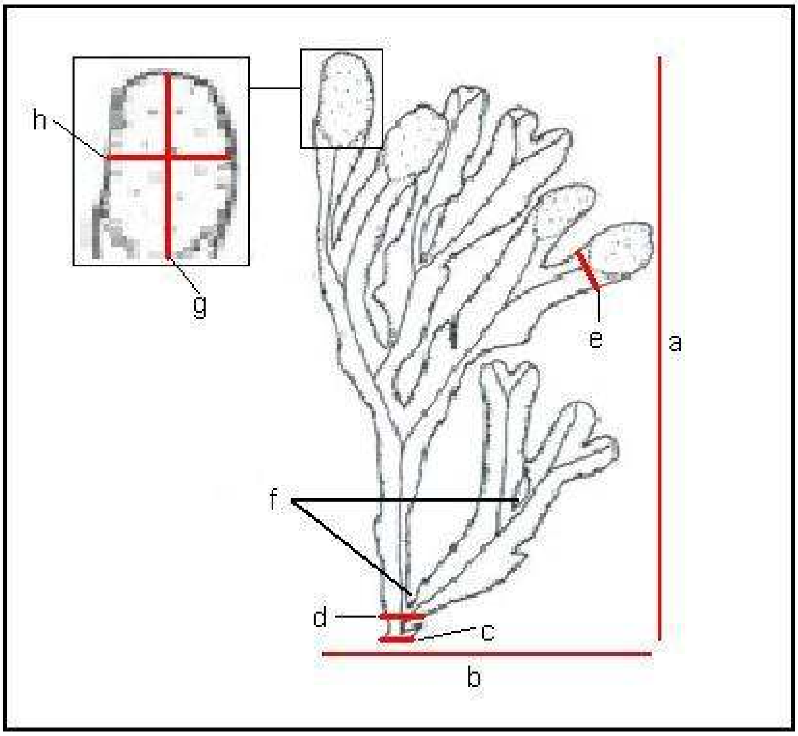

Figure 7: *Measured morphological parameters*

Besides the above listed two new parameters were introduced for future reference:

- Receptacle number- number of receptacles per sample, counted by hand.
- Plant area- the area the plant covers when it is laid out (not the sum of the area of individual branches) was done using the ImageJ© 1.40g area calculating function.

3.4 Data analysis

Data from morphological measurements were analyzed using the program SPSS Release 11.0.1. (SPSS Inc. Chicago, IL), which incorporates the method of MANOVA (Multivariate analysis of variance).

The continuous variables were considered under parametric statistics, which require variables to follow known distributions. The Kolmogorov-Smirnov test was used to determine whether the data set is a good fit to a normal distribution. The processing of data in this manner is used to determine whether the statistical techniques considered for the analysis of the data are adequate. The key parameter gathered from this is the so called ‘2-tailed P’ or asymptotic significance: if this number is below 0.05, the distribution of data is significantly different from normal, while if it is above 0.05 the data can be considered normally distributed.

Boxplots provide a quick visual summary of variance among groups. Furthermore, all the groups within a single factor are arrayed on the same axes, making comparisons easier and providing some evidence about the shape of distribution. Boxplots were used to compare each group using a four-number summary: the median, the 25th and 75th percentiles, and the extreme values (statistical outliers), if present. The heavy black line inside each box marks the 50th percentile or median of the distribution. The median is a measure of the center of the data, with half the values below the median and half the values above it. The median is not sensitive to outlying variables and it varies quite a bit among the boxplots. The lower or upper hinges, or box boundaries, mark the 25th and 75th percentiles (the interquartile range) of each distribution, respectively. Extreme values are marked with an asterisk (*).

3.5 Data comparison

When the gathering and analyzing of data had been finished, the focus was again turned to the study of Reyes & Sansón (1999), from which the corresponding results they had obtained were extracted. This was done by isolating their results for the corresponding months (March, April, May, June), calculating the average values and comparing them with the results from this study. In this part of the study the research of Niell *et al.* (1987) is also included, since they had measured some of the same parameters and is therefore suitable for comparison. Due to the fact that this study was conducted almost 25 years ago, it could help establish a more detailed chronological relationship between the populations of *F. spiralis* and surface seawater temperatures.

4 RESULTS

4.1 Distribution and field observations

GPS coordinates of the visited locations where populations of *F. spiralis* had been reported in the past:
Gran Canaria
Taliarte (27° 59’ 3.15”N; 15° 22’ 2.44”W)
Gáldar (28° 10’ 10.07” N; 15° 41’ 24.26” W)
Salinetas (27° 59’ 3.72”N; 15° 22’ 34.83”W)
Tufia (27° 57’ 42.45”N; 15° 22’ 43.37”W)
Arinaga (27° 52’ 33.25”N; 15° 22’ 51.54”W)
Agaete (28° 6’ 22.80” N; 15° 42’ 40.90” W)
San Nicolas de Tolentino (28° 0’ 27.75” N; 15° 49’ 9.38” W)
Las Canteras (28° 07’ 50.36” N; 15° 26’ 59.12” W)
Tenerife
La Tejita (28° 1’ 46.13” N; 16° 33’ 6.23” W)
Garachico (28°22'30.32"N; 16°45'54.59"W),
Caleta de Interian (28°22'36.21"N; 16°47'46.77"W)
Las Galletas (28° 0'18.29"N; 16°39'20.94"W)
Poris de Abona (28° 9'11.76"N; 16°25'50.52"W).

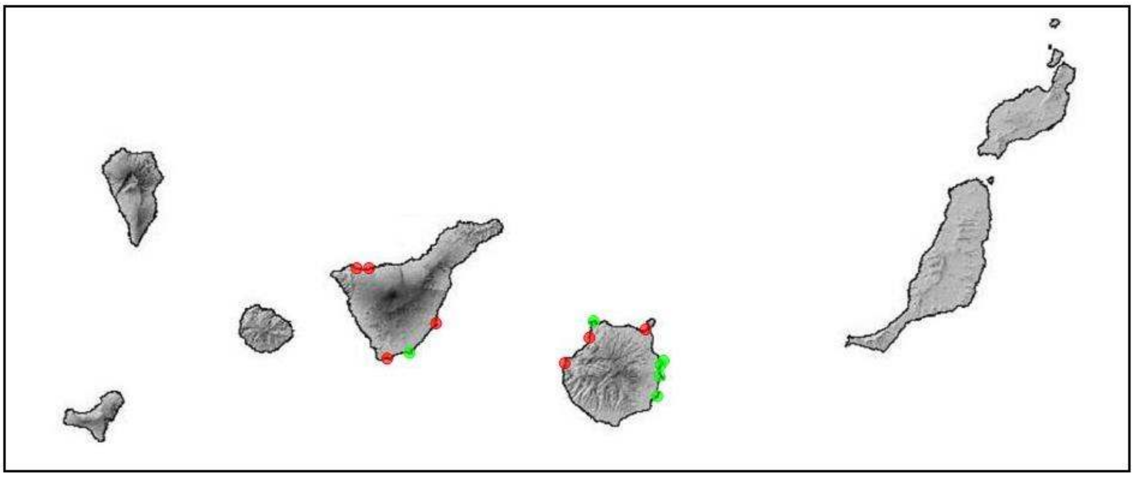

Figure 8: *Distribution of F. spiralis in Gran Canaria and Tenerife. Green dots indicate where the populations have been observed; Red dots indicate where the species was reported in the past, but is now absent.*

4.1.1 Taliarte

F. spiralis was found near Taliarte on a broad rocky platform on the north side of the Port of Taliarte. The platform is exposed to moderate wave action, and in the periods of low tide to strong winds and heavy sun radiation. *F. spiralis* was present initially in two and in the later months in three bigger patches surrounded by a few small patches, no larger than half of a square meter. The samples were taken from the three bigger patches i.e. zones:

Zone 1: this zone was perpendicular to the shoreline located at about 1.5-2.5 meters above the low tide mark. The population was mostly uniform, with a few smaller patches surrounding the main population. In March it had a total area of 7x2 m, which expanded by the end of the sampling to 11x9 m, where the initial population was still prominent, with a higher number of smaller patches scattered around it. The zone was divided into three bands parallel to the shoreline, to see if there are significant differences since the time of submergence differed from one end of the population to the other. No significant differences among the bands were found in the end, which is probably due to the fact that all three bands were distributed within one vertical meter, and consequently the submergence times did not differ enough to make a distinction.

Figure 9: *Sampling site in Taliarte, 28.6.2010 (Zone 1).*

Zone 2: this zone was also parallel to the beach, but located slightly higher in the upper intertidal region. The rocky surface there was a bit more diverse, with more areas of shading and protection from the wind. In March a small population was encountered there, spanning 2x3 m, which by July produced a number of small patches around it, growing to about 15x4.5 m with significant areas of barren rock separating the patches.


Figure 10: *Sampling site in Taliarte, 28.6.2010 (Zone 2).*

Zone 3: in March a few small separate patches (no bigger than 1 m², respectively) of *F. spiralis* were observed about 20 m south (parallel to the beach) of Zone 1, that were situated in the same littoral region. Due to the small size of the population no samples were gathered at that time, but the extent of the population increased and in April the sampling of that zone begun as well. By July the zone spread to 11x5 m composing of one main population about 3x4 m in size, surrounded by a number of approximately 1 m² patches.


Figure 11: *Sampling site in Taliarte, 28.6.2010 (Zone 3).*

4.1.2 Gáldar

Close to the small town of Gáldar in the northwest of the island, a substantial population of *F. spiralis* was encountered at Punta del Cangrejo, where the populations were situated on a very diverse volcanic rock surface. The shoreline is exposed to strong wave action and in the periods of low tide to winds and sun radiation. Because of the very different environmental conditions provided by the non-uniform surface of the shoreline we differentiated three sampling areas:

Zone 1: situated about 15 m from the edge of the rocky platform where the waves brake and consequently directly exposed to strong waves in periods of low to medium tide. The *Fucus* colonies were located on a slightly tilted rocky platform in the eulittoral zone and therefore submerged for longer periods of time. In March 4 distinct bands have been recorded (3.5x2, 3.5x1, 5.8x2 and 9x2.5 m, respectively), which by June expanded (5.5x2.5, 4x3, 7x2.5 and 10x3 m, respectively) and almost became one uniform population, connected via small patches scattered in between the 4 main populations.

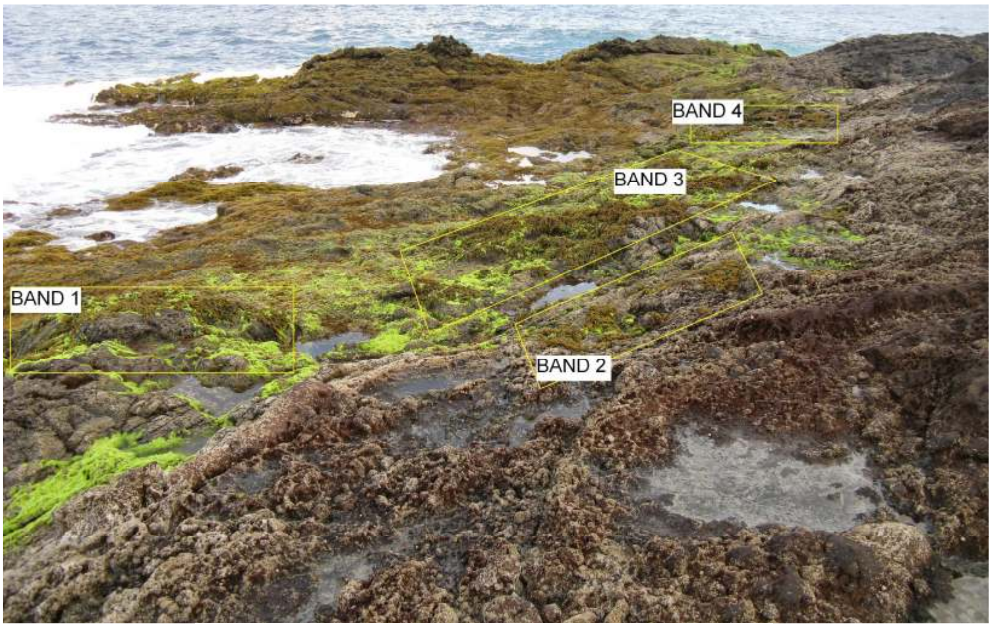

Figure 12: *Sampling site in Gáldar, 15.3.2010 (Zone 1).*

Zone 2: consisted of a single population on a semi-exposed, slightly elevated rocky ridge, located in the eulittoral zone. The reef stands about 30 m from the edge of a rocky platform where the waves brake at low tides, which offers a certain degree of protection from the waves, but on the other hand reduces the time the plants are submerged. In March the size of the population was measured at 7x5 m, which by June expanded to 11x5 m with a number of patches no bigger than 1 m² occupying the rocks surrounding the main population.

Figure 13: *Sampling site in Gáldar, 15.3.2010 (Zone 2).*

Zone 3: a substantial population of *F. spiralis* was observed 30- 50 m from the edge of the rocky platform in the littoral fringe where the algae were subjected to very modest wave action, but spent most of their time emerged, subjected to long drying periods and plenty of sun radiation. The main population occupied a band of 8x3.5 m in March, expanding to 8.5x4 m by June. The main band was surrounded by a great number of smaller patches stretching dozens of meters along the coastline, but never surpassing the elevation of the biggest population.

Figure 14: *Sampling site in Gáldar, 15.3.2010 (Zone 3).*

4.1.3 Salinetas

In the south of the Port of Taliarte a small population of *F. spiralis* was encountered, spread over about 2 m². The population was located in the upper intertidal, but was very poorly developed and deemed too small to sample.

Figure 15: *Fucus spiralis colony in Salinetas.*

4.1.4 Tufia

In Tufia there was almost no sign of *F. spiralis*, just two small patches measuring around 2 dm², which also weren't taken to the laboratory for analysis due to insufficient populations.

4.1.5 Arinaga

In Arinaga, on the west side of the island, much reduced populations of *F. spiralis* were encountered in Punta de la Sal, that weren't plentiful enough for analysis.

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4.1.6 Other localities on Gran Canaria

In other locations on Gran Canaria (Agaete, Las Canteras, San Nicolas de Tolentino) no evidence of *Fucus spiralis* were found.

4.1.7 La Tejita

In the south of Tenerife a population of *F. spiralis* was found in La Tejita beach, located in the municipality of Granadilla de Abona. The population was situated on a rocky ridge in the upper eulittoral zone, where it was subject to low wave action and modest time of submersion. Exposure to solar radiation in March was moderate since the sun was blocked until about 11AM by a high-rising rock formation on west side of the ridge.

The colony was mostly one solid population measuring approximately 14x2 m, with some additional small patches scattered around the near vicinity.

Figure 16: *Sampling site in La Tejita, 16.3.2010.*

4.1.8 Other localities on Tenerife

On Tenerife a number of locations where Reyes and Sansón (1999) reported populations of *F. spiralis* were visited (Garachico, Caleta de Interian, Las Galletas and Poris de Abona), but no evidence of the specie’s presence was found there.

4.2 Gross morphology of the thalli

The Kolmogorov-Smirnov test (results in the table below) demonstrates that most of the results were normally distributed. The exception where the data did not appear to be normally distributed was the plant area. For that reason the data was not taken in account, but still noted as a comparison for future studies.

Table 1: *One-sample Kolmogorov-Smirnov test for the gathered data. The values shown in red do not correspond to a normal distribution.*

One-Sample Kolmogorov-Smirnov Test									
		Maximal (vertical) length of sample (cm)	Maximal (horizontal) width of sample (cm)	Proximal width at the holdfast (cm)	Medial width at the first branching (cm)	Width of the branches below the receptacles (cm)	Plant area (cm^2)	Average length of the receptacles (cm)	Average width of the receptacles (cm)
N		247	247	222	223	247	247	157	157
Normal Parameters	Mean	6,46	7,11	0,39	0,54	0,55	17,29	0,80	0,55
	Std. Deviation	2,40	3,15	0,15	0,21	0,17	11,90	0,25	0,16
Most Extreme Differences	Absolute	0,056	0,064	0,059	0,055	0,05	0,113	0,046	0,063
	Positive	0,056	0,064	0,059	0,055	0,05	0,113	0,042	0,063
	Negative	-0,035	-0,053	-0,024	-0,034	-0,025	-0,094	-0,046	-0,036
Kolmogorov-Smirnov Z		0,886	1,011	0,872	0,817	0,793	1,77	0,579	0,792
Asymp. Sig. (2-tailed)		0,412	0,258	0,432	0,517	0,555	0,004	0,891	0,558

The thalli of *F. spiralis* gathered reached up to 16 cm in total length, but differed significantly depending on sampling locations as well as different seasons in which the sampling took place. The plants consisted of one to several more or less dichotomously branched axes arising from a single holdfast. The average total number of dichotomies in a single plant was 10, but differed greatly with the larger specimens developing up to 30 dichotomies. The average thalli developed about 3 receptacles, with the maximum of 27 receptacles counted in a single plant.

4.2.1 Taliarte

The thalli in Taliarte had an average length of 6.03±1.65 cm, displaying the monthly minimum in April (4.75±1.11 cm) and the maximum in June (6.99±1.89 cm). The average total width of the plants was 6.50±2.42 cm with a minimum in March (4.58±1.36 cm) and a maximum in June (7.84±3.11 cm). The average width of the branches just above the holdfast was 0.37±0.13 cm (min. in April: 0.25±0.08 cm, max. in May: 0.45±0.13 cm), just below the first branching 0.56±0.2 cm (min. in April: 0.41±0.09 cm, max. in March: 0.75±0.27 cm) and just below the receptacles 0.66±0.14 cm (min. in April: 0.57±0.1 cm, max. in March: 0.82±0.2 cm). The average area the plant covered* was measured at 11.67±16.99 cm², with a minimum in April (9.86±5.25 cm²) and a maximum in June (24.67±16.48 cm²). The average number of total dichotomies counted was 8.6±5.68, where the minimum occurred in March (3.75±3.51) and a maximum in June (13.2±6.54). The receptacle count yielded an average of 3.18±4.66, with a minimum of 1.25±1.53 occurring in March and in June a maximum of 7.88±6.00. The receptacles were on average 0.92±0.21 cm long and 0.61±0.21 cm

* the data gathered with this measurement was not normally distributed and is therefore subject to reasonable doubt.

wide (min. and max. length were in April (0.81±0.26 cm) and March (1.02±0.22 cm), respectively; min. and max. width were in July (0.64±0.1 cm) and April (0.59±0.15 cm), respectively).

4.2.2 Gáldar

In Gáldar the thalli displayed an average length of 7.86±2.25 cm, with the monthly minimum in May (6.83±1.44 cm) and the maximum in March (9±3.02 cm). The total width of the plants averaged at 8.93±2.84 cm with a minimum in March (7.75±2.59 cm) and a maximum in April (10.16±2.70 cm). The average width of the branches above the holdfast was 0.42±0.15 cm (min. in March: 0.39±0.19 cm, max. in June: 0.51±0.13 cm), below the first branching 0.56±0.18 cm (min. in March: 0.43±0.16 cm, max. in June: 0.69±0.17 cm) and just below the receptacles 0.47±0.13 cm (min. in March: 0.35±0.13 cm, max. in May: 0.55±0.11 cm). The average area the plant covered* had an average of 21.16±10.92 cm², with a minimum in March (14.73±6.29 cm²) and a maximum in June (25.68±12.7 cm²). The average number of total dichotomies counted was 13.04±5.96, where the minimum occurred in March (11±6.34) and a maximum in June (15.08±5.56). The receptacle count yielded an average of 2.4±2.11, with a minimum of 1.00±1.72 occurring in March and in April a maximum of 3.62±2.64. The receptacles were on average 0.63±0.2 cm long and 1.01±4.45 cm wide (min. and max. length were in March (0.39±0.1 cm) and May (0.73±0.2 cm), respectively; min. and max. width were in March (0.35±0.1 cm) and May (0.53±0.23 cm), respectively).

4.2.3 La Tejita

In La Tejita only one sampling episode was conducted early in the season, so the monthly minimum and maximum data were not gathered. The plants' average length in March was 2.8±0.46 cm, the width of the thalli measuring 2.58±0.45 cm. The width of the plant above the holdfast was 0.21±0.09 cm, at the first dichotomy the width was 0.18±0.8 cm and just below the receptacles it was measured at 0.37±0.07 cm. The plant area* covered 3.17±0.81 cm², the average number of dichotomies was 6.23±2.97. Because the samples gathered in Tenerife were all compressed and dried prior to measuring the receptacles were no longer clearly visible and were therefore not counted or measured.

* the data gathered with this measurement was not normally distributed and is therefore subject to reasonable doubt.

4.3 Monthly comparison of measured morphological parameters between Taliarte and Gáldar

Following is a series of box plots presenting the value of measured parameters in relation to the month of sampling. The values are the monthly averages together with the corresponding standard deviation, depicted in blue for Taliarte and green for Gáldar.

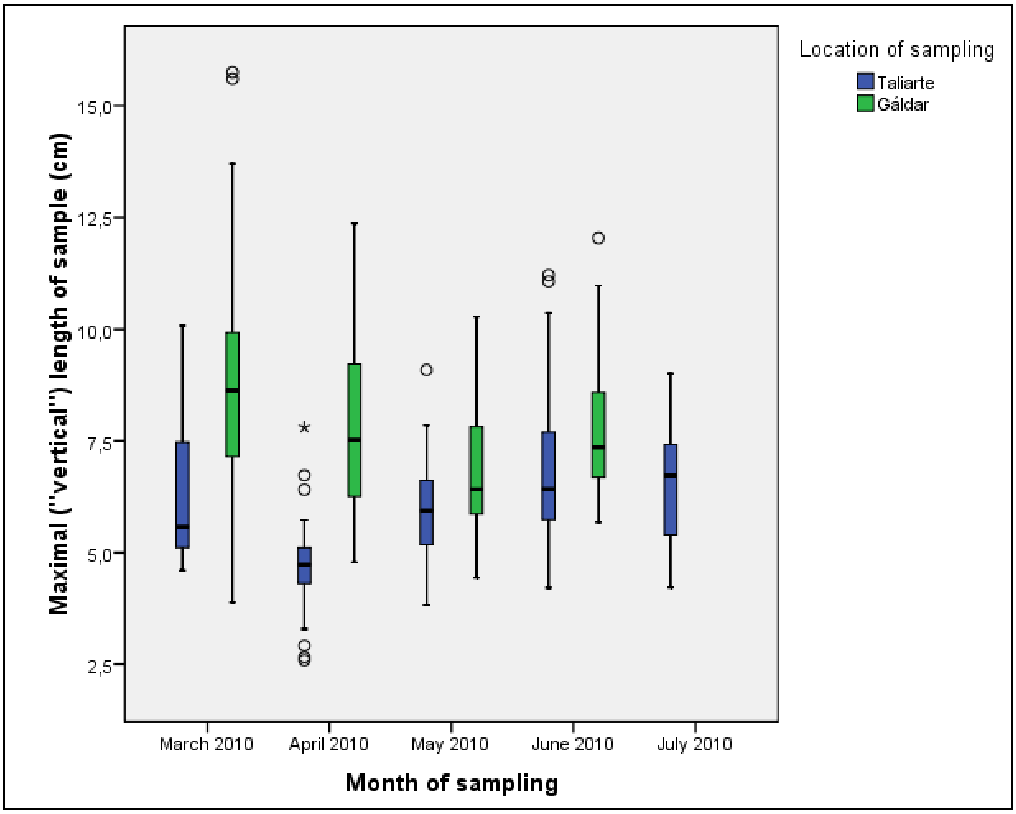

Figure 17: *Monthly average length of thalli for the populations in Taliarte and Gáldar.*

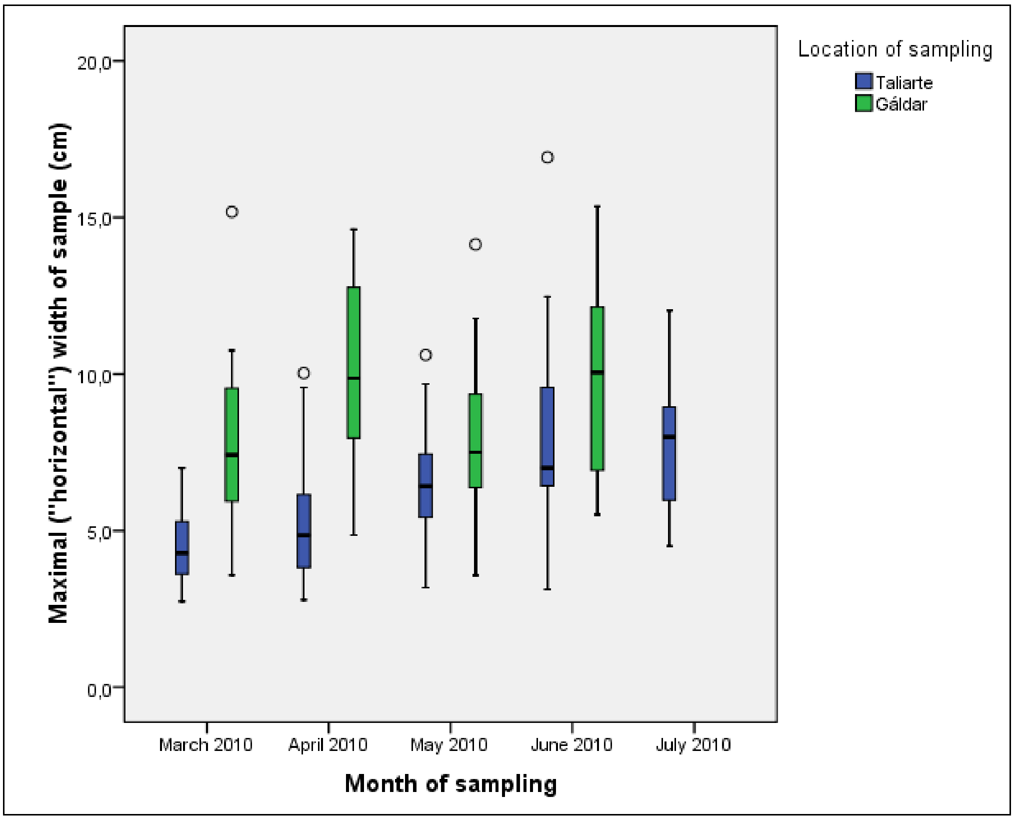

Figure 18: *Monthly average total width of thalli for the populations in Taliarte and Gáldar.*

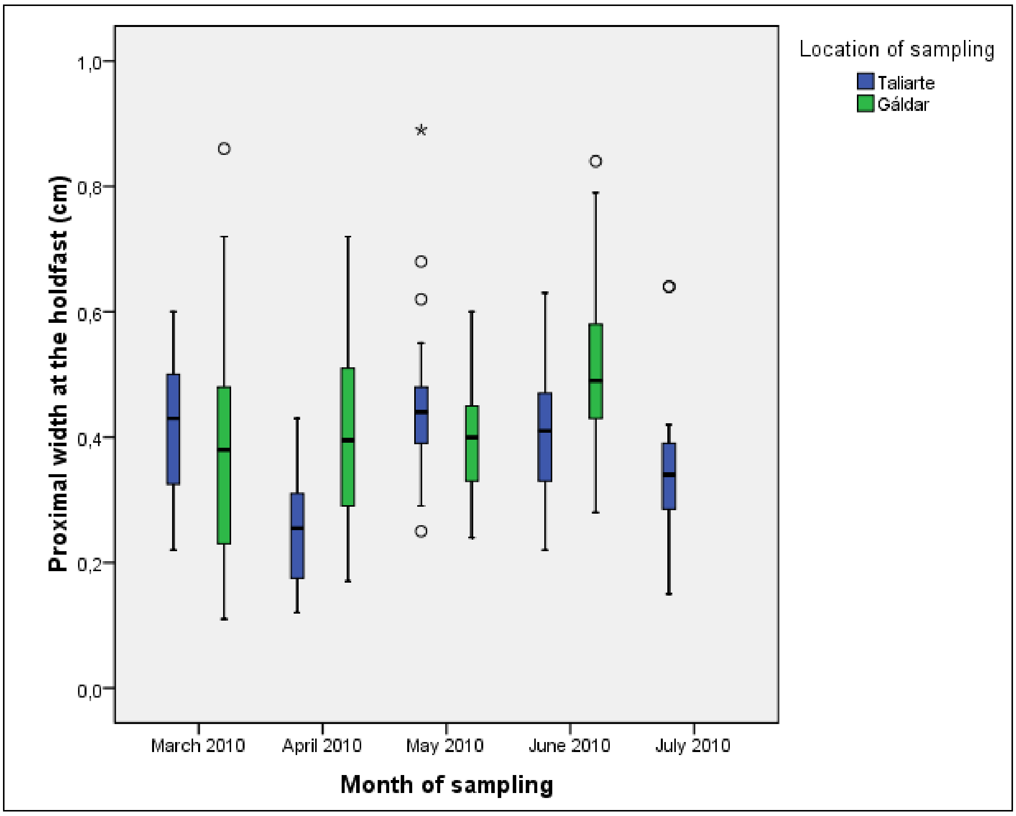

Figure 19: *Monthly average width of thalli measured just above the holfast in the populations in Taliarte and Gáldar.*

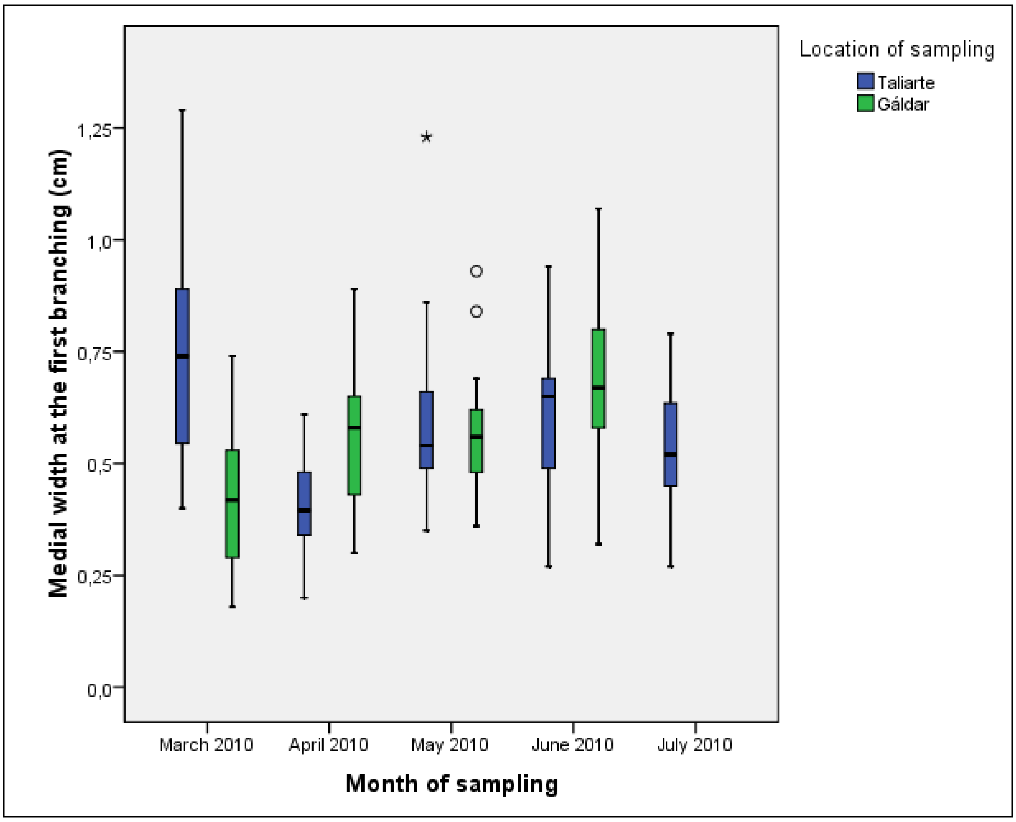

Figure 20: *Monthly average width of thalli measured just below the first dichotomy in the populations in Taliarte and Gáldar.*

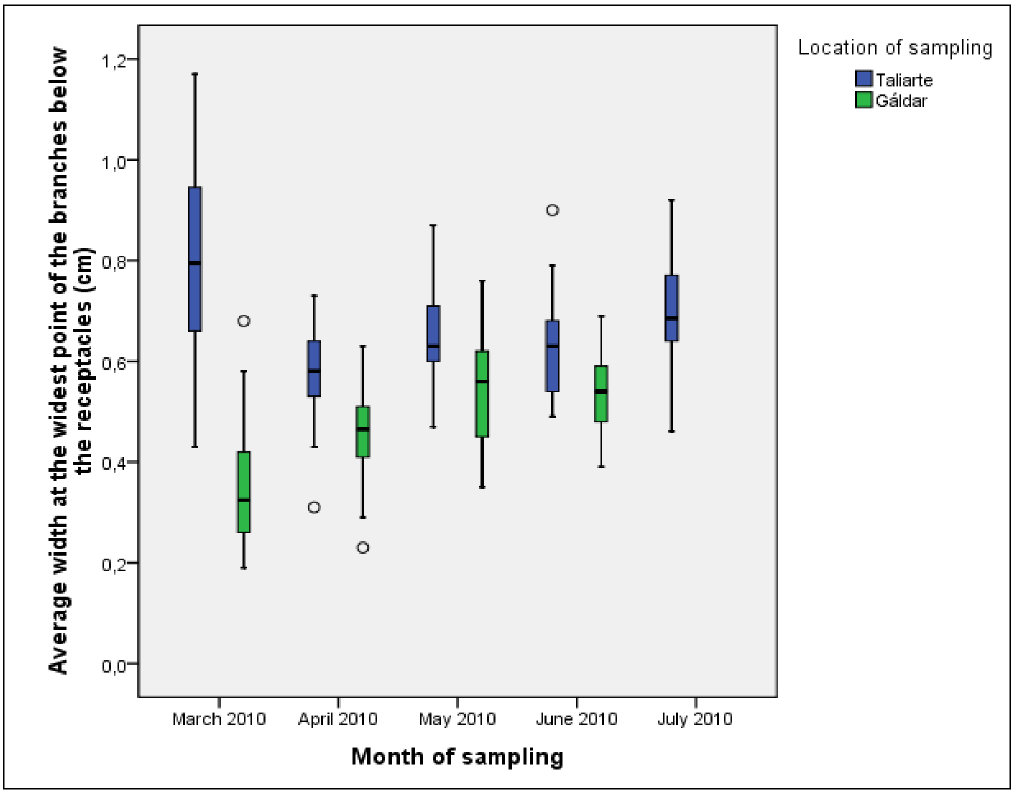

Figure 21: *Monthly average width of the thalli below the receptacles in the populations in Taliarte and Gáldar.*

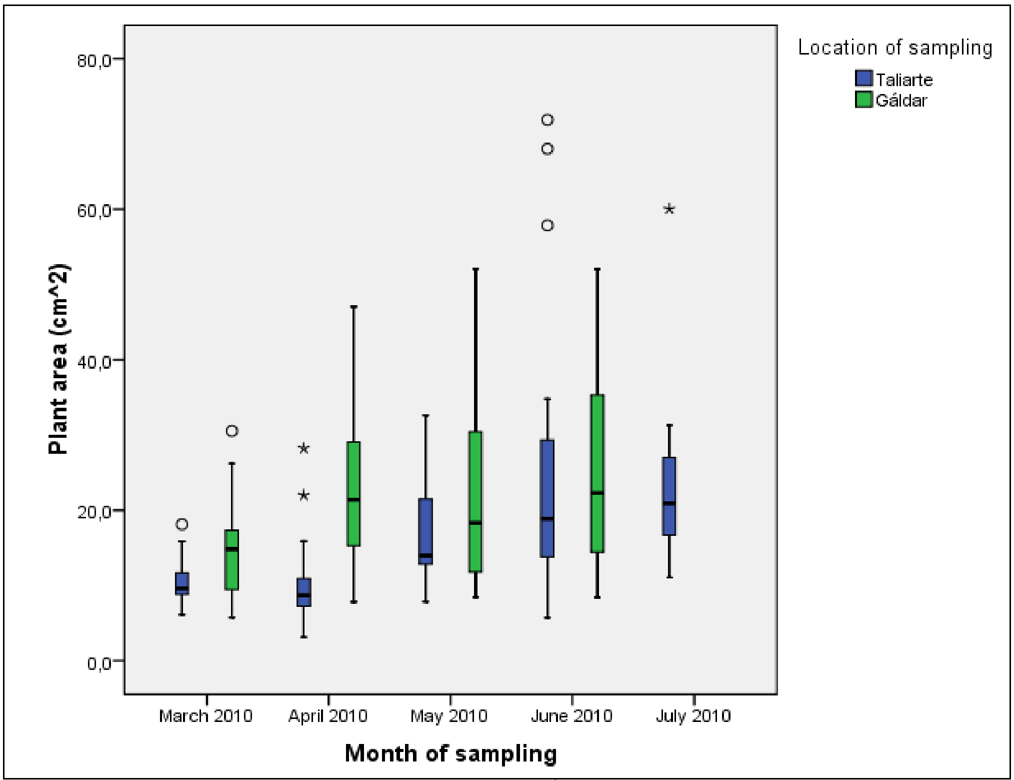

Figure 22: *Monthly average plant area[*] for the populations in Taliarte and Gáldar.*

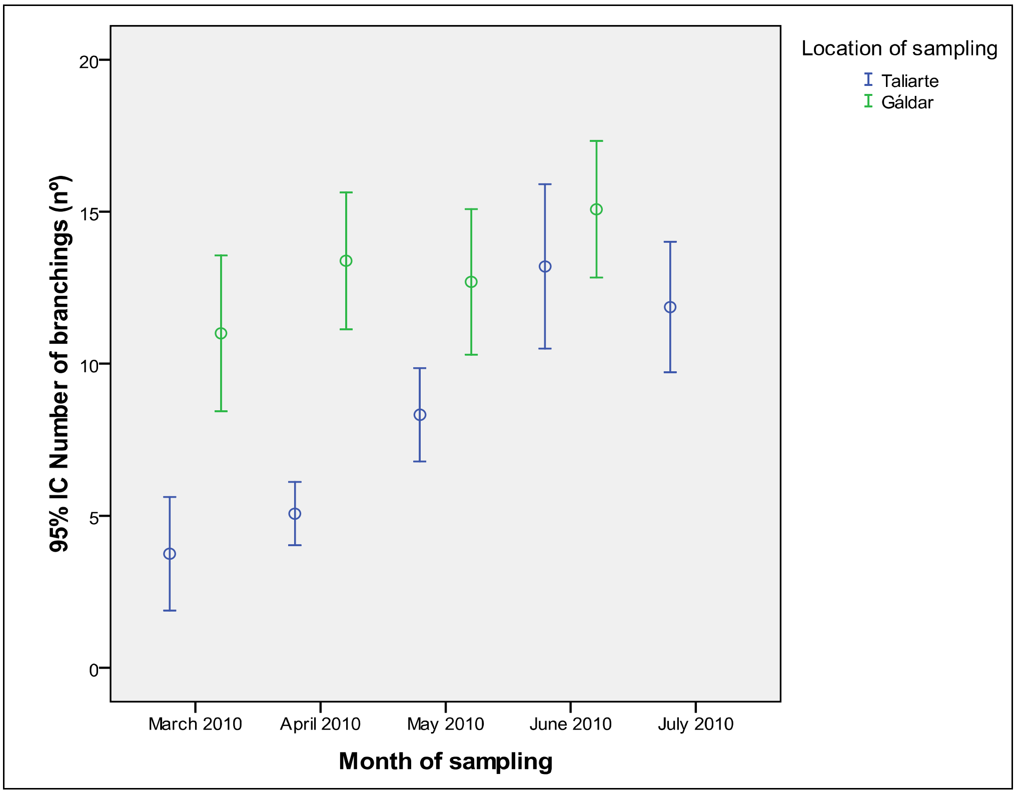

Figure 23: *Monthly average of the number of branchings in a single alga in populations in Taliarte and Gáldar.*

[*] the data gathered with this measurement was not normally distributed and is therefore subject to reasonable doubt.

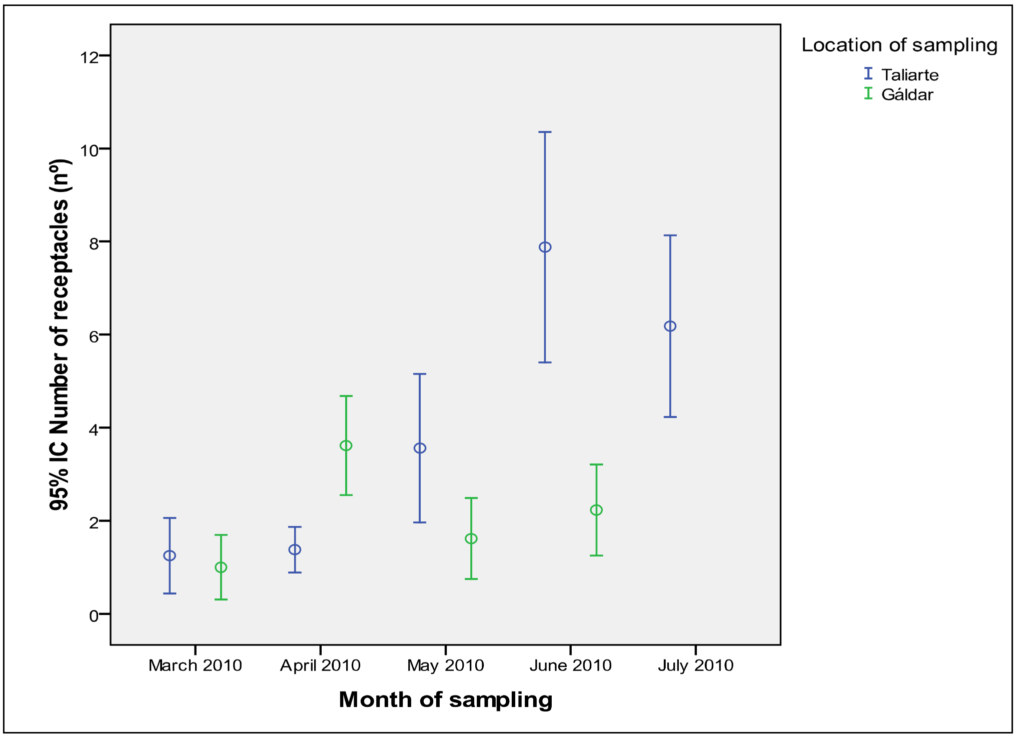

Figure 24: *Monthly average number of receptacles in the populations of Taliarte and Gáldar.*

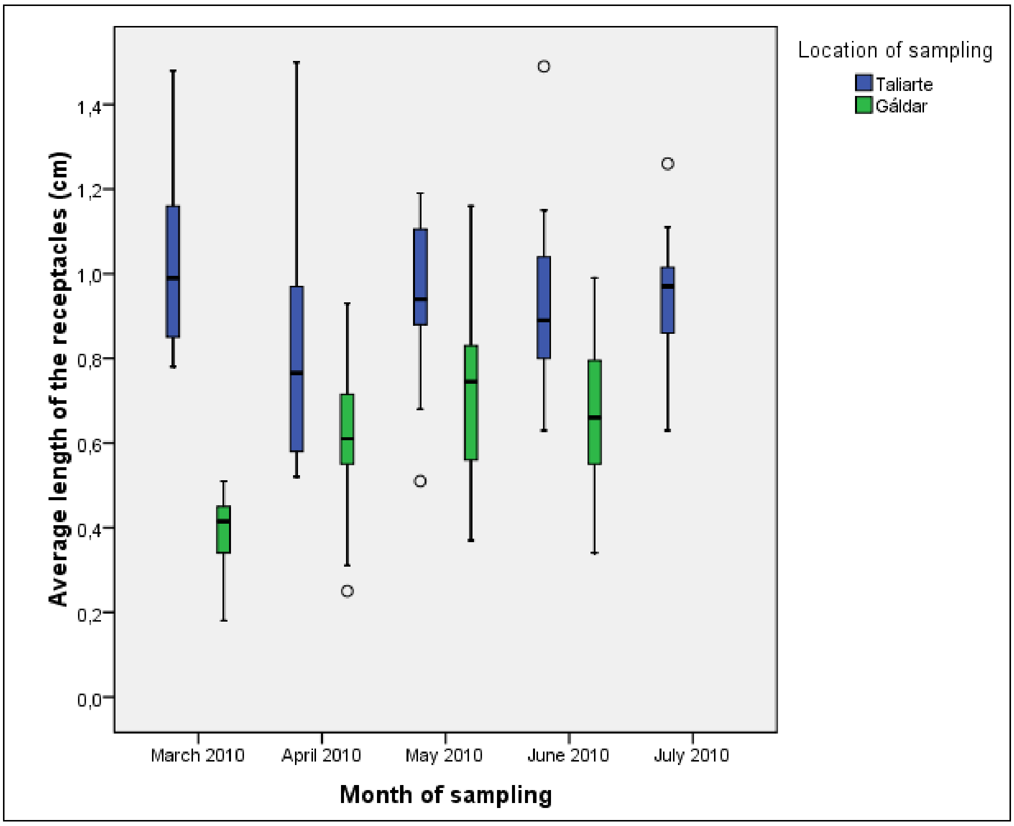

Figure 25: *Monthly average length of receptacles in Taliarte and Gáldar.*

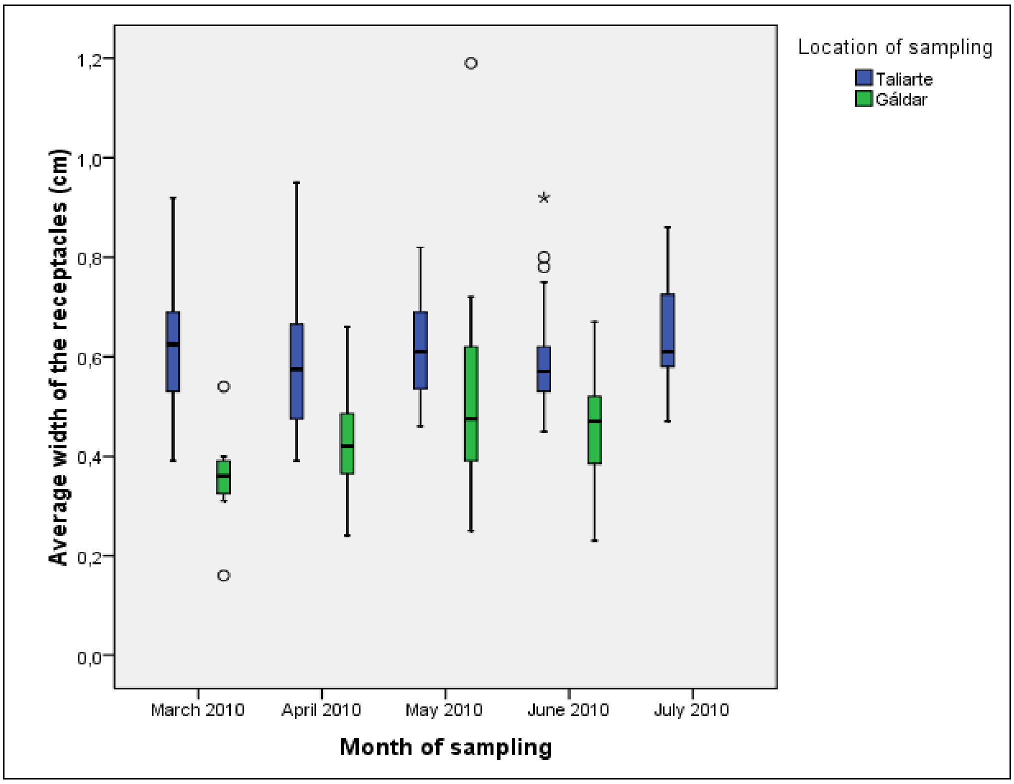

Figure 26: *Monthly average width of the receptacles in the populations of Taliarte and Gáldar.*

4.3.1 Trends

Maximal length of the thalli shows a slightly ascending trend in Taliarte from April to July, whereas in Gáldar a descending trend from March until May was noticed. The results of the measurements of the width of the plants showed the same tendencies. In the samples from Gáldar all three measurements of the branches (proximal, medial and distal region) showed a rising trend during the course of this experiment, which cannot be said for Taliarte, where none of the mentioned parameters showed any significant inclinations. Plant area measurements, although doubtful because of their abnormal distribution, displayed a growing trend in both localities throughout the experiment, as did the total number of dichotomies. The number of receptacles per plant also showed a rising tendency with abnormalities in June (Taliarte) and April (Gáldar). The receptacle length and width did not show any obvious trends in either of the locations during the course of this experiment.

4.3.2 Comparison with previous studies

Below are the morphological attributes of *F. spiralis* gathered in two previous studies that are comparable with the results obtained from the current study, followed by a summary of the results gathered.

Table 2: *Morphological features of Fucus spiralis in Tenerife, extracted from the study of Neill et al. (1987)*

Neill *et al*., 1987						
	Platycarpus				*Limitaneus*	
Unit- cm	**El Médano**	Std.dev.	**Puerto de la Cruz**	Std.dev.	**Güímar**	Std.dev.
Max. Length	8.8	1.7	11.7	2.9	4	1.3
Max. Width						
WP (ap)						
WM (am)						
WD (ad)	0.94	0.17	1.1	0.22	0.67	0.16
Area [cm²]						
Dichotomies #	4.3	1.7	5.4	4.3	0.13	0.5
Receptacles #						
LR	1.69	0.31	1.82	0.51	1.13	0.32
WR	0.9	1.2	1.17	0.21	0.79	0.14

Table 3: *Morphological features of Fucus spiralis in Tenerife, extracted from the study of Reyes & Sansón (1999).*

Reyes & Sansón, 1999				
Unit- cm	El Médano	Std.dev	Garachico	Std.dev.
Max. Length	10.76	1.52	9.57	1.44
Max. Width				
WP (ap)	0.22	0.07	0.18	0.06
WM (am)	0.79	0.16	1.01	0.18
WD (ad)	1.01	0.11	1.15	0.19
Area [cm²]				
Dichotomies #	3.08	0.81	2.20	0.58
Receptacles #				
LR	1.21	0.21	1.87	0.36
WR	0.83	0.15	1.21	0.23

Table 4: *Morphological features of Fucus spiralis gathered in this study (2010).*

Current study, 2010						
Unit- cm	Taliarte	Std.dev.	Gáldar	Std.Dev.	La Tejita	Std.dev.
Max. Length	5.95	1.72	7.75	2.33	2.80	0.46
Max. Width	6.42	2.44	8.81	2.91	2.58	0.45
WP (ap)	0.36	0.14	0.42	0.15	0.21	0.09
WM (am)	0.55	0.20	0.55	0.18	0.18	0.08
WD (ad)	0.65	0.15	0.47	0.13	0.37	0.07
Area [cm²]	16.85	11.48	20.98	10.83	3.17	0.81
Dichotomies #	8.46	5.61	12.96	5.88	6.23	2.97
Receptacles #	3.17	4.58	2.12	2.38		
LR	0.91	0.22	0.61	0.21		
WR	0.60	0.13	0.44	0.15		

The results show that the plants grew to a bigger average length in both previous studies (conducted 19 and 23 years ago, respectively) than in the current study. The result is the same for all locations, where the measurements were taken. The pattern is similar with the width of the branches, except for the width measured above the holdfast, where my measurements yield greater values. The number of dichotomies counted was difficult to compare, since the method of counting used might have been different between the studies, but after examining the graphs from the results of Reyes & Sansón (1999) the trend of increasing number of dichotomies in the same time period was observed in both studies. The length and width measurements of the receptacles also yielded greater values in the previous studies.

After comparing the data from Reyes & Sansón (1999), the data for the sampling site of El Médano (which is very close to the sampling location La Tejita) could be extracted in the month of March (when the samples from La Tejita were taken) and discovered that the data obtained by Reyes & Sansón (1999) indicate much bigger plants. Below is a table of results comparable between the studies.

Table 5: *Comparing the results gathered in 1999 and March of 2010 in El Médano and La Tejita, respectively.*

Unit- cm	Reyes & Sansón (1999)		Current study	
	El Médano	Std.dev.	La Tejita	Std.dev.
Max. Length	10.13	1.52	2.80	0.46
WP (ap)	0.22	0.08	0.21	0.09
WM (am)	0.74	0.13	0.18	0.08
WD (ad)	1.03	0.09	0.37	0.07

5 DISCUSSION

5.1 Distribution of *F. spiralis*

Reviewing all the available bibliographic data regarding the global distribution of *F. spiralis* confirmed that the Canary Islands represent the southernmost limit of the species' geographical range, with the exception of some populations found nearby in Morocco (Dangeard, 1949; Gil-Rodriguez & Socorro Hernández, 1986; Ribera *et al.,* 1992) which are presumed to be the consequences of cold water upwelling from the North Atlantic current (Barton *et al*., 2000), which allows the species' presence at such low latitude. Another atypical characteristic regarding global distribution is the presence of the species in the North Pacific, as reported by numerous authors (Lindstrom, 1977; Scagel *et al*., 1989; Coyer *et al*., 2006), since the distribution data suggests that the species is of an Atlantic origin. Following Coyer *et al.* (2006), the occurrence of *F. spiralis* in the North East Pacific is thought to be a consequence of three possible scenarios: Firstly, that a *F. spiralis* ancestor evolved in the North Pacific from a hermaphroditic *Fucus* predecessor, which dispersed through the Arctic Ocean and radiated within the North Atlantic. One alternative scenario suggests that a *Fucus distichus* ancestor existed in the North Pacific, which dispersed into the North Atlantic where it radiated into *F. spiralis* and *F. distichus*. This implies a trans-Arctic dispersal of *F. spiralis* from the North Atlantic to the North Pacific. The third scenario, described by Serrão *et al*. (1999), points to a possibility of human induced introduction of *F. spiralis* to the North Pacific, which is suggested by the restricted range of the population in that region. From a dispersal standpoint it is important to realize that *F. spiralis* is a hermaphroditic species, which greatly increases the chances of successful dispersal, because only one individual is necessary to colonize new habitats (Baker, 1955), and that all *Fucus* species have eight eggs per oogonium, whereas other Fucales have one to four, which also increases the possibility of colonization.

The available literature did not allow for a very detailed reconstruction of the species' local distribution in recent decades, because the studies which include comprehensive cartographic distributions of *F. spiralis* in the Canary Islands are scarce. On the other hand previous studies have revealed plenty of information regarding local distribution resulting from discontinous, location-specific sampling episodes. The works of Reyes & Sansón (1999) and Neill *et al*. (1987) that were followed, provided a fair amount of applicable data, but the fact that their studies were conducted more than 15 and 20 years earlier, respectively, leaves a lot of room for error resulting from annual fluctuations and possible migrations of the populations. In order for this study to be more comprehensive it should be conducted over a longer period of time, where the colonies of *F. spiralis* would be monitored on a continous basis, spatially as well as chronologically. I aspire that this study will serve as a more solid foundation for future studies of this sort since, on its own, it is not conclusive enough. Nevertheless the results gathered in this study point to a substantial decline in populations of *F. spiralis* in Gran Canaria and especially in Tenerife, as 13 locations where the species had been reported in the past have been examined, and of those only 6 had colonies present, of which only 3 had substantial populations. We can observe that the demise of populations is much greater in Tenerife which can possibly be attributed to the fact that the surface water temperatures rise in the westerly direction across the archipelago (Barton *et al.,* 2000), which would result in warmer waters around Tenerife. Unfortunately the data gathered on water temperatures did not portray a high enough resolution to make that assumption, as noticeable temperature changes can occur within a relatively small area due to local water dynamics and freshwater springs.

While the distribution results show a strong decline in the observed populations, there is little data on the rest of islands' coastline. There is a possibility that the missing populations could have simply migrated elsewhere, although it is not very likely since they require a very specific type of coastline to flourish. Another thing is that, as mentioned by Hernández (2008), although the overall trend of surface water temperatures indicates an increase, there are strong annual fluctuations and further analysis should be made to see whether the demise in populations is permanent or just temporary.

5.2 Morphology

Morphological characteristics such as size, color, degree of branching and number of receptacles are strongly dependent on environmental factors and several authors have reported polymorphic properties of the species (Russell, 1978; Gomez-Garreta *et al.,* 2001; Niell *et al.,* 1987). This study has also shown that *F. spiralis* occurs in a variety of different shapes and sizes, thus confirming what the authors had written. The results that we have gathered appear to show an odd trend in the development of the thalli from Gáldar as they seem to have been getting shorter as the study progressed. As stated, the species' morphological development may be a result of many different factors and in this case the unexpected trend could have derived from a mistake in the sample gathering method, or it can in fact be a consequence of environmental features such as changes in submergence time (wave action is a lot weaker in the summer and the water only reaches the algae during the highest of tides), or the increase of solar radiation along with air temperatures and the accompanying changes in water temperatures. Apart from that, assumptions had to be made using average values acquired in only four months of field observations, not the entire life cycle of the thalli, which leaves a lot of room for errors to be made and it is very likely that year-round measurements would have yielded different results.

Another atypical trend appeared when measuring the plant area. The dilemma in this case arises from the abnormal distribution of the data, which is most likely the consequence of the inappropriate method used for its measurement. As none of the previous studies had measured plant area, I was hoping to introduce a new parameter to the data, but failed, since the measurements are considerably unreliable as well as irreproducible, especially when the complexity of the samples increased with their development. This could have been avoided by splitting the samples into single branches and then measuring them, rather than spreading the branches out as much as possible. This procedure only works with samples that have a small number of branches, as with more dichotomous samples the branches can overlap. If the samples had been split into branches, it would be possible to measure the area by hand as well, but it would be a very lengthy process during which the samples would get ruined. Therefore it was decided not to proceed with this process since the samples were needed for herbarium sheets and there would be nothing to compare the potential results with. In the end the measurements were conducted as originally planned, but the results gathered are of little value.

Similar to area measurements, another parameter was introduced that had not been previously studied, the receptacle count, but in this case the counting was done manually and that leaves little room for significant errors to be made, since the procedure is quite simple. In this case the results clearly show how much the thalli of *F. spiralis* can differentiate, even within very similar environments. Solid overall conclusions regarding the number of receptacles cannot be made, due to the lacking of data for the rest of the samples' life cycle, but the results are not to be discarded since for the most part they indicate a nice ascending trend throughout the experiment, as expected.

When comparing Gáldar and Taliarte, the two populations that were followed throughout the experiment, subtle differences were found between them. In Gáldar the algae on average grew bigger, wider and more branched, but possessed fewer and smaller receptacles than the samples gathered in Taliarte. Due to insufficient data it was not possible to determine exactly why these differences occurred, but they are most likely consequences of the surrounding environmental conditions. If we assume the thalli in Gáldar had formed more receptacles later on in the year, we can conclude that the population there is more prosperous, but the reproductive stages of their development are delayed compared to the thalli from Taliarte. This can be the result of a number of environmental features such as substrate (Lewis, 1972), water temperature and salinity (Munda; 1964, 1967), nutrients in the water (Knight and Parke, 1950) and photoperiod (Naylor, 1956) but, as stated, the available data did not allow for further assumptions to be made.

When examining the morphological features of the populations from La Tejita, the single viable population found on Tenerife, it became evident that the specimens there were significantly smaller and less developed than in Gran Canaria. If we consider that along with the fact that they were absent in all other localities we had visited, we can conclude that *F. spiralis* seems to be disappearing from the island of Tenerife all together.

Concerning the *platycarpus* / *limitanius* distinction, not enough data was at my disposal to make conclusions, since Reyes and Sansón (1999) noted that the species' form varies in relation to seasonal variation. Overall it appears that the samples from both localities in Gran Canaria were displaying more *platycarpus*-like features, whereas in Tenerife they appeared to have taken on the *limitanius* form. Unfortunately, in order to make that conclusion, I would have to operate with the morphological measurements for the rest of this year and preferably past years as well.

5.3 Comparison with previous studies and the relation to global climate change

In comparison with the data extracted from previous studies (Reyes & Sansón, 1999; Niell *et al.*, 1987), smaller and less developed plants have been observed in all locations. The only exception was the dichotomy count, as this parameter was significantly greater in this study, which is most likely due to the poor description of the method used for counting in the previous studies. Although the number of branchings may seem like an unambiguous result, it is certainly not the case, especially when dealing with more complex samples, where it is sometimes difficult to tell whether the specimen consists of one or more individuals, since often a number of thalli grow from a single holdfast. That is why the experience of the sampler plays a vital role in the quality of the end results.

Ultimately, while comparing the obtained results with Reyes & Sansón (1999) and Niell *et al.* (1987), noticeable changes in the populations of *F. spiralis* in Canary Islands over the past 20 years have been observed in the species' morphological features and especially in its distribution. The populations of *F. spiralis* seem to have decreased quite dramatically in their abundance and are less developed as well. Furthermore there is strong evidence that suggests that in that period the surface seawater temperatures in the area have risen significantly (Hernández, 2008). However, since there are many factors influencing the distribution as well as the morphology of algae (Niemeck & Mathieson, 1976), no conclusions regarding the origin of the changes in the populations observed could be made. Besides the long-term surface water warming I propose there might be a correlation between the occurrence of extremely warm periods on a short time scale, which do not significantly affect the average surface water temperature, but might have a noticeable impact on the state of the populations. While there is a strong possibility that the changes observed in this study are in fact consequences of global climate change, I did not operate with sufficient data to make that conclusion, but I recommend that this subject be further studied in the future. Another evidence that points to the correlation between the disappearing of *F. spiralis* in the Canaries and the rising of surface water temperatures around the islands is the fact that the westernmost islands don't have any populations left at all (R. Haroun, personal communication, 2012). The surface water temperatures there are higher than in Tenerife or Gran Canaria, so the species' disappearance from those islands is strong evidence towards confirming the presumption that rising surface water temperatures are the main factor causing the disappearance of *F. spiralis* from the Canary Islands.

In the study of Lima *et al.* (2007), which also investigated the relationship between surface seawater temperature and the distribution of algae, they found that in nearby Portugal a number of intertidal algal species displayed shifts in their biogeographical range in the past 40 years, also presumably due to temperature increase. *F. spiralis* however, which is also present there and was included in the aforementioned study, did not show trends of migration. I presume this is the consequence of lower seawater temperatures in the area, with maximum average values reaching about 19°C, which is significantly lower than the temperatures around the Canarian archipelago and well within *F. spiralis*' comfort zone. But, according to Lima (2007), the seawater temperatures around the Portugese coastline have risen by as much as 1,53°C in the past 50 years and if this trend continues, there is a possibility of the disappearing of *F. spiralis* from this area as well, but this is not likely to happen in the near future.

This research was designed to determine the presence or absence of *F. spiralis* in the Canary Islands, taking into consideration the work of Reyes & Sansón (1999), but it became evident that neither their nor our study were comprehensive enough to make any solid assumptions regarding population changes in the last decades as consequences of global climate. The fact remains that *Fucus spiralis* populations are disappearing from the Canarian shores, with reduced number of extant populations, probably as a consequence of climate change, i.e. temperature rise in recent decades, but more meteorological data are needed to confirm this field result and try to find a correlation between plant extinction and temperature increase. That is why I hope that rather than drawing definite conclusions from this study it will serve as a template for future research, since I am of the opinion that the topic is worth investigating further.

6 CONCLUSIONS

1. – This study has confirmed a worrying decline in the populations of *Fucus spiralis* on the Canarian islands of Gran Canaria and Tenerife over the last 20 years.

2. – The remaining populations of *Fucus spiralis* on Gran Canaria and Tenerife show morphologically less developed individuals than were recorded 19 and 23 years ago, respectively.

3. – Although the aforementioned changes could have derived from surface water temperature differences caused by global warming, there is insufficient data to confirm this.

4. – This study, although inconclusive, should serve as a template for future research in assessing the impact of global warming on marine ecosystems.

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8 ANNEXES