Featured Article

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Trends of the seagrass *Cymodocea nodosa* (Magnoliophyta) in the Canary Islands: population changes in the last two decades

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Summary: Seagrass meadows perform essential ecosystem functions and services. Though the meadows are globally deteriorating, numerous regressions remain unreported as a result of data fragmentation. *Cymodocea nodosa* is the most important seagrass in shallow coastal waters of the Canary Islands. No study has so far investigated temporal population trends at the entire archipelago scale. Using data collected in the past 23 years by local companies, public authorities and research groups, the population trends of *Cymodocea nodosa* were analysed over the past two decades at the scales of islands, island sectors and meadows. During this period, a prevalence of negative trends was revealed for three seagrass demographic descriptors (seagrass shoot density, coverage and leaf length) at the three scales, evidencing an overall deterioration in seagrass meadow integrity. These results suggest the need to develop correct management strategies to guarantee the conservation of this seagrass and the meadows it creates.

Keywords: seagrass; population trend; temporal patterns; change rates; Canary Islands; Atlantic Ocean.

Tendencias de la fanerógama marina *Cymodocea nodosa* (Magnoliophyta) en las Islas Canarias: cambios poblacionales en las dos últimas décadas

Resumen: Las praderas de fanerógamas marinas suministran funciones y servicios esenciales para los ecosistemas. A pesar de que dichas praderas están globalmente deteriorándose, numerosas regresiones son aún desconocidas como resultado de la falta de datos. *Cymodocea nodosa* es la fanerógama marina más importante en aguas someras de las costas del Archipiélago Canario. No obstante, ningún estudio ha analizado las tendencias temporales de sus poblaciones a escala de todo el archipiélago. Utilizando datos recogidos durante los últimos 23 años por empresas, administraciones públicas y grupos de investigación, se analizaron las tendencias de las poblaciones de *Cymodocea nodosa* durante las últimas dos décadas en el Archipiélago Canario a la escala de islas, sectores insulares y praderas individuales. A lo largo de este periodo, se observa una prevalencia de tendencias negativas para tres descriptores demográficos (densidad de haces, cobertura y longitud de hoja), evidenciando un deterioro general en la integridad de las praderas. Estos resultados sugieren la necesidad de desarrollar estrategias de gestión correctas para garantizar la conservación de las praderas constituidas por esta planta marina.

Palabras clave: fanerógamas marinas; tendencia poblacional; patrones temporales; tasa de cambio; islas Canarias; Océano Atlántico.

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INTRODUCTION

Seagrass meadows perform essential ecosystem functions and services at a global scale; seagrasses sink C and support food webs (Duarte et al. 2008), provide shelter for associated fauna (Pollard 1984, Bell and Pollard 1989, Espino et al. 2011), produce O_2 (Peduzzi and Vukovic 1990), stabilize sediments and protect coastlines from turbulence (Hemminga and Nieuwenhuize 1990, Cabaço et al. 2010). However, seagrass meadows are experiencing a rapid decline worldwide (Orth et al. 2006). Waycott et al. (2009) estimated a global loss of 29% of their coverage between 1879 and 2006, with an increasing trend of annual loss of 7% since 1990. The function of seagrasses as habitat-formers or ecological engineers (sensu Jones et al. 1994) suggests that their conservation is a primary issue for preserving a healthy marine environment.

Coastal ecosystems are among those subjected to the largest human pressures in the world (Halpern et al. 2008). Anthropogenic pressures on the coast are a fundamental reason for the global deterioration of seagrasses (Orth et al. 2006, Waycott et al. 2009). Human activities are responsible for many disturbances of seagrass meadows, such as water contamination (Waycott et al. 2009), increased turbidity and eutrophication (Burkholder et al. 2007), mechanical damages on the seabed (Francour et al. 1999, Milazzo et al. 2004, Ceccherelli et al. 2007), including boat anchoring (Montefalcone et al. 2008), and alterations of the habitat due to coastal works (Pérez-Ruzafa et al. 1991).

Cymodocea nodosa (Ucria) Ascherson is a seagrass distributed across the Mediterranean Sea and along the nearby eastern Atlantic coasts, including the Macaronesian oceanic archipelagos of Madeira and the Canary Islands (Mascaró et al. 2009, Oliva et al. 2012). This marine spermatophyte plays a fundamental role as a result of its function as 'habitat engineer', particularly in the Canary Islands (Reyes et al. 1995, Tuya et al. 2014a, b). It is generally located along the eastern and southern coasts of the islands, sheltered from the dominant oceanic swells from the north and northwest (Reyes et al. 1995, Pavón-Salas et al. 2000). This seagrass forms extensive, but often fragmented, subtidal meadows (Barberá et al. 2005, Espino et al. 2008, Tuya et al. 2013a). In the Canary Islands, *C. nodosa* shows a seasonal pattern in vitality, with a summer peak in shoot density and biomass (Reyes et al. 1995, Tuya et al. 2006, 2013a), similar to what has been observed for the Mediterranean Sea (Terrados and Ros 1993, Rismondo et al. 1997).

Two previous studies have reported a declining trend of *Cymodocea nodosa* meadows at Gran Canaria Island (Tuya et al. 2013a, 2014a). The present study aims to extend the results of these studies by determining the temporal trends (from 1991 to 2013) of *C. nodosa* meadows across the entire Canary Islands archipelago through the analysis of three structural (demographic) descriptors of *C. nodosa* meadows: seagrass shoot density, coverage and leaf length. This study is important from a conservation perspective. The Canary Islands autonomous Government recently introduced a new environmental law that reduced the protection status of *C. nodosa* (BOC nº 112, Law 4/2010 of the Canary Islands Catalogue of Protected Species) to the category: "species of interest for Canarian ecosystems". At present, this seagrass is only protected within marine protected areas, i.e. "Areas of Special Conservation" under the EU 'Natura 2000' network. Our analysis therefore contributes to a critical appraisal of this recent legislative decision.

MATERIALS AND METHODS

Data source

We compiled all published data including any of the following three seagrass structural descriptors: seagrass shoot density, cover and leaf length of *Cymodocea nodosa* at any place in the Canary Islands between 1991 (first record) and 2013 (last record). A variety of sources were used, including scientific publications and above all grey literature, mainly reports carried out by local environmental and public bodies (see supplementary material, Table S1). Each datum corresponded to a sampling within a particular geo-referenced area at a specific depth and time. Coverage was estimated as the percentage of the area in which the presence of *C. nodosa* was detected, typically through 25- or 50-m-long transects. Shoot density was expressed as number of shoots per area (m^2). Leaf length corresponds to the mean height (in cm) of leaves. It is worth noting that for each data source the available records did not always include the three demographic descriptors.

Data analysis

Collected data were analysed at three different spatial scales: "island", "island sector" and "meadow". Firstly, data were temporally analysed separately for each island, resulting in 6 data sets: El Hierro, La Gomera, Tenerife, Gran Canaria, Fuerteventura and Lanzarote (including meadows around La Graciosa Islet as well). La Palma was excluded due to the lack of records of *Cymodocea nodosa* after the renovation of the Santa Cruz port, the only location on the island where the presence of *C. nodosa* was recorded (Pavón-Salas et al. 2000). This corresponds to the analysis at the scale of islands by pooling all data within each island according to the date (year) of collection.

Secondly, the coastal perimeter of each island was divided according to its geographic orientation (Fig. 1); data sets were therefore temporally analysed independently for each sector within each island, excluding El Hierro, where the presence of *C. nodosa* was recorded only to the northeast of the island. It should be noted that in several cases entire areas of the coastal perimeter were excluded from the study due to the absence of records. This represents the "island sector scale" analysis.

Thirdly, meadows with the largest time data sets at each island were analysed separately. The meadows included had to meet at least one of the following two criteria: the presence of records collected over more

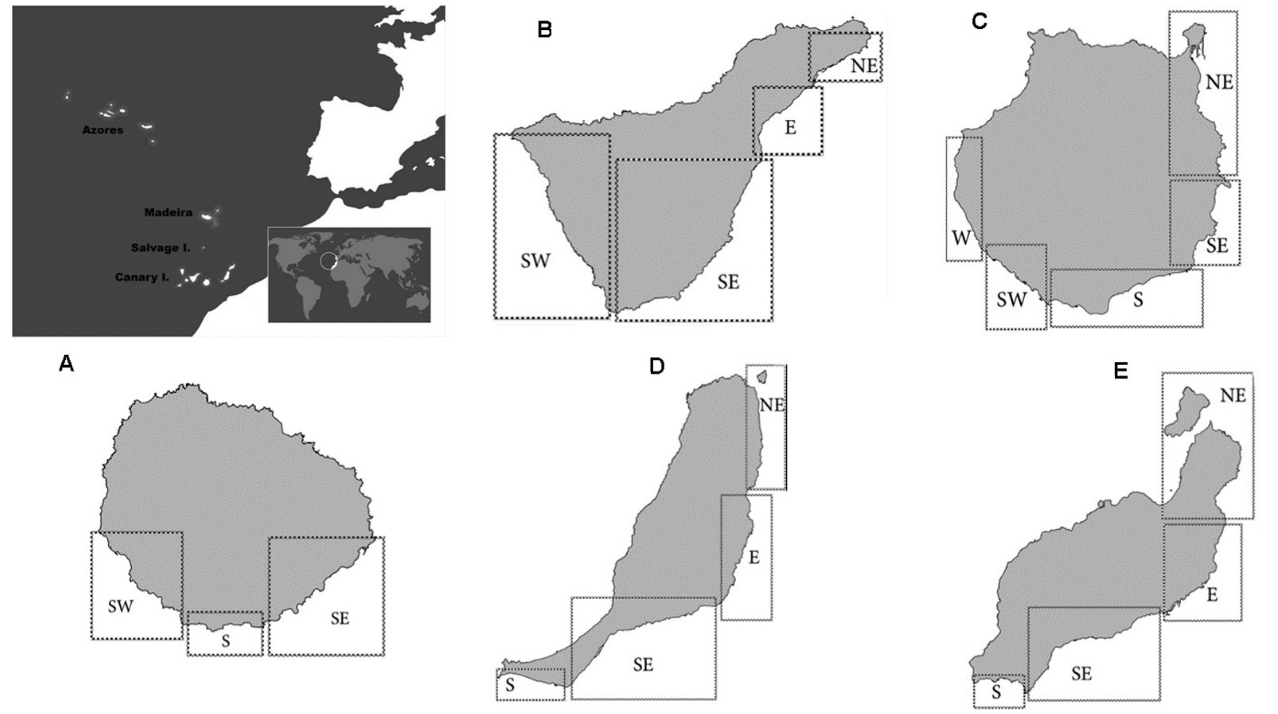

Fig. 1. – Location of the study area and division of each island into sectors of different orientation at La Gomera (A), Tenerife (B), Gran Canaria (C), Fuerteventura (D), and Lanzarote (E).

Table 1. – Summary of data compilation for each island.

	Time period	Studies	Surveys	Sectors	Meadows
Gran Canaria	1994-2013	19	231	NE-SE-S-SW-W	22
Tenerife	1991-2012	14	178	E-SE-SW	21
Lanzarote	2001-2013	5	109	NE-E-SE-S	19
Fuerteventura	2003-2013	3	128	NE-E-SE-S	19
La Gomera	2004-2009	4	25	SE-S-SW	4
El Hierro	2005-2009	4	13	-	2

than 3 years and a total amount of at least 20 records over time. Following this criterion, 3 meadows were selected for Tenerife (Granadilla, El Médano and Igueste), 5 for Gran Canaria (Pasito Blanco, Maspalomas, Playa del Inglés, Gando and Arinaga) and 2 for both Fuerteventura (Gran Tarajal and Playa Blanca) and Lanzarote (Playa Quemada and Guasimeta). In El Hierro and La Gomera, no meadows met these criteria, so no analysis was carried out. A total of 12 meadows were thus examined.

Since data sets were recorded at different annual seasons and *Cymodocea nodosa* naturally shows maximum vitality and senescence seasons during spring/summer and autumn/winter, respectively (Reyes et al. 1995, Tuya et al. 2006), data were standardized to prevent potential confounding seasonal changes from influencing the results. Data from two studies describing the intra-annual monthly variation in the vitality of *C. nodosa*, Tuya et al. (2006) and Reyes et al. (1995), were used for this purpose: the former reported seasonal patterns of shoot density and leaf length in a meadow from Lanzarote Island, while the latter reported annual patterns of shoot density in a meadow from Tenerife Island. The patterns identified by Tuya et al. (2006) were used to standardize data from the eastern islands (Gran Canaria, Fuerteventura and Lanzarote), while the patterns by Reyes et al. (1995) were used to standardize data from the western islands (Tenerife, La Gomera, El Hierro). For each structural descriptor, a relative value on a scale from 0 to 1 was established for each month, assigning 1 to the month with the highest value and, subsequently, attributing a proportional value to the remaining months. To standardize descriptors for a given meadow according to the month of collection, each datum was then multiplied by the corresponding relative value (0-1). For the three seagrass structural descriptors, at each of the three spatial scales a regression line was adjusted to statistically test the trends over time (i.e. over the last two decades).

RESULTS

The analysis compiled 684 records from 49 studies carried out during a period of 23 years, between 1991 and 2013. A total of 87 meadows at 6 islands of the Canarian Archipelago were considered (Table 1 and Table S1).

Island scale

The linear regressions that tested the significance of the temporal trends of the three structural descriptors at each island indicated that linear adjustments were statistically significant in 9 of the 18 cases (Fig. 2). For

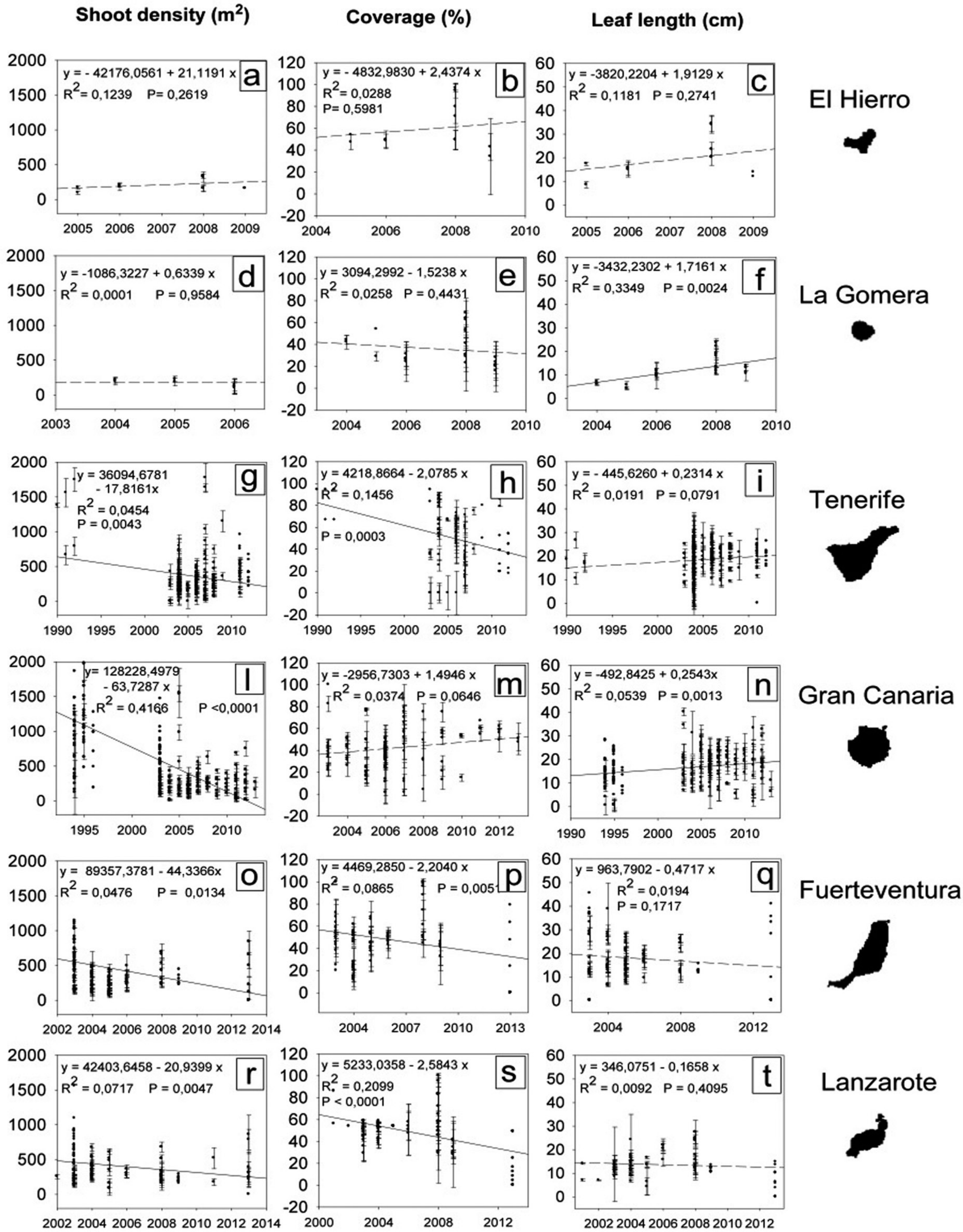

Fig. 2. – Changes over time of *C. nodosa* seagrass shoot density, coverage and leaf length in the Canary Islands. Linear regression equations are included (the R^2 coefficient was included to indicate the precision of the adjustment) for each structural descriptor and island. Solid lines denote statistically significant ($P<0.05$) adjustments, while dotted lines correspond to statistically non-significant adjustments ($P>0.05$).

these 9 significant cases, 2 corresponded to increasing trends over time, while 7 corresponded to decreasing trends over time.

At El Hierro, all regressions were statistically non-significant (Figs 2A, B, C), i.e. no temporal pattern was evidenced. For La Gomera, shoot density (Fig. 2D) and

Table 2. – Summary of significant results (P<0.05) for the analysis of temporal changes of the structure of *C. nodosa* seagrass meadows at the island sector scale.

Island	Sector	Shoot density (m^2)	Coverage (%)	Leaf length (cm)
Gran Canaria	NE	Decreasing	No trend	No trend
	SE	Decreasing	No trend	No trend
	S	Decreasing	No trend	Increasing
	SW	Decreasing	No trend	No trend
	W	No trend	No trend	No trend
Tenerife	E	Increasing	No trend	No trend
	SE	Decreasing	Decreasing	No trend
	SW	Increasing	Increasing	No trend
Lanzarote	NE	Decreasing	Decreasing	Decreasing
	E	No trend	No data	No data
	SE	No trend	No trend	No trend
	S	No trend	Decreasing	No trend
Fuerteventura	NE	No trend	No trend	No trend
	E	No data	No data	No data
	SE	Decreasing	Decreasing	No trend
	S	No trend	No trend	No trend
La Gomera	SE	No trend	No trend	Increasing
	S	No data	No data	No data
	SW	No trend	No trend	No trend
El Hierro	-	-	-	-

Table 3. – Summary of significant results (P<0.05) for the analysis of temporal changes of the structure of *C. nodosa* meadows at the scale of meadows.

Island	Meadow	Shoot density (m^2)	Coverage (%)	Leaf length (cm)
Gran Canaria	Pasito Blanco	No trend	No trend	No trend
	Maspalomas	No trend	No trend	No trend
	Playa del Ingles	Decreasing	No trend	Increasing
	Gando	Decreasing	No trend	No trend
	Arinaga	Decreasing	No trend	No trend
Tenerife	Granadilla	No trend	Decreasing	No trend
	El Medano	Decreasing	Decreasing	No trend
	Igueste	No trend	No data	No trend
Lanzarote	Playa Quemada	No trend	No trend	No trend
	Guasimeta	No trend	No trend	Decreasing
Fuerteventura	Gran Tarajal	No trend	No trend	No trend
	Playa Blanca	No trend	No trend	No trend
La Gomera	-	-	-	-
El Hierro	-	-	-	-

coverage (Fig. 2E) showed no particular trend, i.e. regressions were statistically non-significant, while leaf length (Fig. 2F) showed an overall increase over time. At Tenerife, both seagrass shoot density (Fig. 2G) and coverage (Fig. 2H) were found to be decreasing over time, while leaf length (Fig. 2I) showed a statistically non-significant pattern. At Gran Canaria, seagrass shoot density (Fig. 2L) decreased over time, while leaf length (Fig. 2N) increased; seagrass coverage (Fig. 2M) showed no significant trend. At both Fuerteventura and Lanzarote, seagrass shoot density and coverage (Fig. 2O, P, R, S, respectively) decreased significantly over time, while leaf length (Fig. 2Q, T, respectively) showed no statistically significant temporal pattern.

Island sector scale

Of the 20 sectors examined at 5 of the 6 islands (Table 2), seagrass shoot density was found to be significantly decreasing in 7 cases, increasing in 3, and not showing any trend in 10 cases; seagrass coverage was found to be significantly decreasing in 4 cases, increasing in 1 case and not showing any trend in 15. Leaf length was found to be significantly decreasing in 1 case, increasing in 2, and not showing any trend in 17 cases.

Meadow scale

Of the 12 meadows examined at 4 of the 6 islands (Table 3), seagrass shoot density was found to be significantly decreasing at 4 meadows and not showing any trend at 8 meadows. Seagrass coverage was found to be significantly decreasing at 2 meadows and not showing any trend at 10 meadows; leaf length was found to be significantly decreasing and increasing at only 1 meadow, and not showing any trend at 10 meadows.

DISCUSSION

Our results identified important changes in the demographic structure of *Cymodocea nodosa* seagrass meadows in the Canary Islands over the last 23 years. Specifically, we have identified a prevalence of decreasing trends in the overall state of *C. nodosa* meadows in the Canary Islands by considering several structural descriptors of seagrass abundance. These results somehow support previous observations of many other studies worldwide (Orth et al. 2006, Waycott et al. 2009, Short et al. 2011) that point towards a deterioration in the state of conservation of seagrass meadows. In addition, these results are in concordance with temporal patterns observed for *C. nodosa* meadows at some of the Canary islands, such as Gran Canaria (Tuya et al. 2013a, 2014a), where a decline in the vitality of *C. nodosa* has been demonstrated in the last decade.

It is worth noting, however, that the capacity to reveal ecological trends considerably differed among the three structural descriptors that we selected to describe temporal changes in the structure of *Cymodocea nodosa* meadows. In turn, we believe there are noteworthy differences in the ability of each descriptor to reflect the status of *C. nodosa* seagrass meadows, in particular between seagrass shoot density and the other two, coverage and leaf length. First of all, seagrass coverage and leaf length can largely vary in the way data are gathered from study to study, while shoot density, on the other hand, is often taken following more standard procedures, i.e. by deploying a quadrat on the marine bottom and counting the number of shoots within. Seagrass coverage corresponds to the percentage of the bottom covered by *C. nodosa*, normally taken along 25-m transects, so it does not take into account the density of seagrass shoots and, most importantly, the overall area occupied by the seagrass. In other words, this descriptor measures the percentage of surface covered by the seagrass, but not the state of the meadow, a condition that, at least in the particular case of *C. nodosa*, is better explained by shoot density (Oliva et al. 2012, Tuya et al. 2014a). Consequently, even if a meadow has undergone regression by reducing its overall area and shoot density and then its integrity, this may not be revealed by the analysis of the coverage. With respect to the leaf length, this biometrical attribute represents a morphological response to prevailing environmental conditions (i.e. water turbidity and hydrodynamics); this parameter can change considerably regardless of a deterioration or improvement of meadow conditions. For example, under increased turbidity and sedimentation, *C. nodosa* may experience a temporal increase in leaf length (Tuya et al. 2002, Tuya et al. 2013b). At Gran Canaria, a densely populated island of the archipelago, seagrass shoot density decreased over time, whereas leaf length increased; this disparity shows the different response of these two descriptors to environmental variability. As a result, at local scales, the most representative structural attribute of *C. nodosa* to describe seagrass meadow integrity, at least from the perspective of temporal variation, is seagrass shoot density. This result apparently contrasts with those obtained by Oliva et al. (2012), who selected alternative structural descriptors of *C. nodosa* to assess the quality of coastal waters. However, the scale of both studies is different. On the one hand, Oliva et al. (2012) aimed at selecting seagrass structural attributes across spatial gradients in coastal water quality. The effect of pollution was better predicted by structural attributes that reflect the consequences of pollution, e.g. above to below-ground ratios). Our study, on the other hand, focused on long-term tendencies, which seemed to be better predicted by seagrass shoot density.

The Canary Islands are densely populated (over 2 million inhabitants [www.ine.es]), including a large tourist pressure (*ca.* 10 million tourists per year, www.gobiernodecanarias.org/istac/temas_estadisticos/sectorservicios/hosteleriayturismo/demanda). The largest decreases in seagrass shoot density and coverage were observed at Gran Canaria, Tenerife, Lanzarote and Fuerteventura, i.e. the most populated islands of the archipelago, with more than 90% of the overall population. In contrast, the islands with the lowest population density (El Hierro and La Gomera) showed stable temporal patterns for all seagrass structural descriptors. Somehow, this outcome points out towards a connection between human pressure and seagrass meadow vitality, as previously reported for Gran Canaria (Tuya et al. 2014a, b). The correspondence between highly populated islands of the Canarian Archipelago and decreased shoot density of the meadows over time strengthens or, at least, does not disprove the observation already indicated by other studies (Orth et al. 2006, Duarte et al. 2008, Waycott et al. 2009, Short et al. 2011) of a negative correlation between the intensity of environmental pressures and seagrass conservation. In the particular case of Gran Canaria, the main human-mediated impacts that correlated with seagrass meadow deterioration were the number of outfalls (mainly sewage discharges) and ports (Tuya et al. 2014a). Moreover, in the last years, blooms of the cyanobacteria *Lyngbya majuscula* have been frequently observed in seagrasses to the south of Gran Canaria, Fuerteventura and Lanzarote (Martín-García et al. 2014). *Lyngbya* is considered an important risk for seagrasses due to its epiphytic growth on seagrass leaves and the production of allopathic substances. Hence, negative interactions between *C. nodosa* and *L. majuscula* should be considered with caution, particularly within the framework of eutrophized environments.

While the analysis at the island scale somehow revealed clear temporal trends, the analyses at the sector and meadow scales showed a large number of statistically non-significant results. This is most likely connected with the replication level of the analyses at the three scales: larger data availability at the island scale lead to higher statistical power for detecting significant patterns. At the sector and meadow scales, however, the smaller amount of data corresponds with a lower statistical power. Despite this, significant patterns had a prevalence of decreasing trends over time at both the sector and meadow scales. These results reinforce the impression of a prevalence of negative trends of *Cymodocea nodosa* in the Canary Islands. The dimension of this study, including a large data set of records (684), different sources (49), and the temporal scale (over two decades), support the reliability of our interpretations. The overall decline experienced by *C. nodosa* meadows represents a further warning and an incentive to encourage research on *C. nodosa* conservation, particularly as a result of the importance of this species as a 'habitat engineer' and its sensitivity to deteriorating environmental conditions, which may be indicative of the state of the marine environment (Oliva et al. 2012).

In summary, this work is another step towards filling the somehow sparse information about seagrass distribution and their temporal patterns, particularly on the western coast of Africa. The deterioration of *Cymodocea nodosa*, the main seagrass species in the study area, that we have reported herein is further evidence of the urgent need for better management of the coastal areas.

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SUPPLEMENTARY MATERIAL

The following material is available through the online version of this article and at the following link:
http://www.icm.csic.es/scimar/supplm/sm04165esm.pdf

Table S1. – Compiled demographic data of *C. nodosa* at each meadow and island, including shoot density, coverage and leaf length. The name of the study/project correspond to the official name, while the name of the enterprise/Admistration that provided the data is in parenthesis, whenever appropiate.