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Drastic decadal decline of the seagrass *Cymodocea nodosa* at Gran Canaria (eastern Atlantic): Interactions with the green algae *Caulerpa prolifera*

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ABSTRACT

The shoot density, leaf length and biomass of the seagrass *Cymodocea nodosa* (Ucria) Ascherson were found to severely decline in the last 17 years in the oceanic island of Gran Canaria (central Eastern Atlantic). Five seagrass meadows were sampled in summer and winter of 1994–1995 and in winter and summer 2011. The decrease in *C. nodosa* correlated with a 3-fold increase in the biomass of the green rhizophytic algae *Caulerpa prolifera* (Forsskål) J.V. Lamoroux over the same time period, although this increase varied notably among meadows. We also documented a negative correlation between the biomass of *C. nodosa* and *C. prolifera* at the island-scale, sampling 16 meadows in 2011. Experimental evidence demonstrated that *C. prolifera* can cause significant negative impacts on *C. nodosa*: plots with total (100%) removals of *C. prolifera* had ca. 2.5 more shoots and 3.5 times more biomass of *C. nodosa*, after 8 months, compared to plots with 50% removals and untouched control plots. Interference by *C. prolifera* appears to partially explain the decay in the abundance of *C. nodosa* populations in Gran Canaria. This study, however, did not identify potential underlying processes and/or environmental alterations that may have facilitated the disappearance of *C. nodosa*.

1. Introduction

On shallow subtidal soft bottoms, seagrasses are the main foundation species from tropical to temperate oceans. The mechanisms behind their influence on community structure are multifaceted, but key ecological functions include modifying local environmental conditions and the provision of food and habitat for a wide range of organisms (Constanza et al., 1997). Conservation of these valuable habitats is therefore important, particularly since seagrass meadows are declining worldwide, mainly in areas of intense human activities (Duarte et al., 2008; Hughes et al., 2009; Kenworthy et al., 2009; Waycott et al., 2009). There is, however, no information on seagrass distribution and abundance patterns from most coasts of the world over the last decades, and so many losses are unknown (Duarte et al., 2008).

Cymodocea nodosa (Ucria) Ascherson is a seagrass distributed across the Mediterranean Sea and the adjacent eastern Atlantic coasts, including the Macaronesian oceanic archipelagos of Madeira and the Canaries (Alberto et al., 2006; Mascaró et al., 2009). Meadows constituted by *C. nodosa* are the dominant vegetated communities in shallow soft substrates throughout the Canaries (Pavón-Salas et al., 2000; Barberá et al., 2005), where they provide food and shelter for diverse invertebrate and fish assemblages (Tuya et al., 2001, 2006; Espino et al., 2011). These meadows are generally located along the eastern and southern coasts of the islands, sheltered from the dominant swells from the north and north-west. *C. nodosa* forms extensive, but often fragmented, subtidal meadows (Reyes et al., 1995a; Pavón-Salas et al., 2000; Espino et al., 2003; Barberá et al., 2005). In this region, *C. nodosa* shows a clear seasonal pattern, with a summer peak in shoot density and biomass (Reyes et al., 1995a,b; Tuya et al., 2006), similar to what has been observed in the Mediterrean (e.g. Terrados and Ros, 1993).

In the Mediterranean, widespread decline of seagrass meadow has often resulted in the replacement by green algae such as *Caulerpa* (Ceccherelli and Cinelli, 1997; Lloret et al., 2005), though the time scale can affect interactions between *C. nodosa* and *Caulerpa*. For example, on the long-term, effects of *Caulerpa* on *C. nodosa* may not be so severe (Ceccherelli and Sechi, 2002). The ecological mechanisms behind these shifts in seagrass abundance (cover) vary between studies. For example, human-induced increases in nutrient loading and suspended sediments in the water column, involving a reduction in water transparency, can locally facilitate the replacement of *C. nodosa* by *Caulerpa prolifera* (Forsskål) J.V. Lamoroux (Lloret et al., 2005; Morris et al., 2009). In other circumstances, competition for nutrients in the sediment has been pointed out as the main ecological mechanism explaining the regression of *C. nodosa* and the concurrent expansion of *Caulerpa* beds (Ceccherelli and Cinelli, 1997).

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Table 1
Geographical description of sites (seagrass meadows, from north to south) sampled for *Cymodocea nodosa* and *Caulerpa prolifera* across the island of Gran Canaria; dates of sampling are included. Sites in bold are those considered for the historical comparison (sampled in both the mid-1990s and 2011), while the rest were only sampled in 2011.

Site	UTM X	UTM Y	Depth (m)	Mid-1990s		2011	
				Winter	Summer	Winter	Summer
Gando	463,434	3,089,688	4	Jan-95	May-95	Feb	Aug
Gando-piscina	464,252	3,089,224	15			Feb	Aug
Gando Castillo	463,105	3,089,320	10			Feb	Aug
Gando-boya	463,760	3,089,133	19			Feb	Aug
Roque de Arinaga	462,589	3,081,567	14	Jan-95	Aug-94	Feb	Sep
Risco Verde	462,095	3,081,237	10	Mar-95	Jul-94	Feb	Sep
Arinaga	460,946	3,081,019	5	Jan-95	Jul-94	Feb	Sep
Arinaga-muelle viejo	461,108	3,080,464	9			Feb	Sep
Arinaga-2	460,863	3,080,742	7			Feb	Sep
Pasito Blanco Playa	439,077	3,069,016	8			Feb	Aug
Pasito Blanco	439,109	3,068,979	8	Dec-94	Aug-95	Feb	Aug
Pasito Blanco-fuera	439,142	3,068,942	9			Feb	Aug
Centro-Com	439,175	3,068,905	10			Feb	Aug
Meloneras-1	439,224	3,068,923	5			Feb	Aug
Meloneras-2	439,386	3,068,553	11			Feb	Aug
Faro Maspalomas	439,550	3,068,460	12			Feb	Aug

In this study, we (i) compared the shoot density, leaf length and biomass of the seagrass *C. nodosa* in 5 seagrass meadows at the oceanic island of Gran Canaria (Canary Islands, eastern Atlantic) between 1994–1995 and 2011. Since we detected a sharp decrease in the abundance (shoot density and biomass) of *C. nodosa* that was partially matched with an increase in the biomass of the green, rhizophytic, native algae *C. prolifera*, we additionally (ii) tested whether the biomass of *C. nodosa* and *C. prolifera* are currently negatively correlated across the island, and in a manipulative field experiment (iii) tested if *C. prolifera* can have a negative effect on *C. nodosa*, i.e. whether removal of *C. prolifera* would increase the abundance of *C. nodosa*.

2. Materials and methods

2.1. Historical comparison

Five seagrass meadows (Table 1) were selected across the entire distribution area of *C. nodosa* in Gran Canaria. Each meadow was between 0.5 and 10 km apart from the adjacent studied meadow to encompass a range of conditions across the island. Each meadow was sampled in 4 occasions (Table 1), including a winter and summer season in 1994–1995, and winter and summer of 2011. On each sampling time, three cores (20 cm of inner diameter) were pushed into the sediment by a SCUBA diver. All materials were then transferred to labelled bags and frozen (−20 °C) until being processed in the lab. For each sample, we counted the number of shoots (shoot density), as well as measured the length of 30 randomly selected leaves. The biomass was separated into leaves and rhizomes and roots subsequently oven-dried (24 h at 70 °C) to obtain dry-weight biomass measurements. The dry biomass of all accompanying macroalgae, mainly the green algae *Caulerpa prolifera*, was also obtained. All measurements were standardized to m^{-2} to facilitate comparisons with other studies, and followed standardized procedures (Bortone, 2000). Temporal differences between years (hereafter mid-1990s vs. 2011), seasons (winter vs. summer) and sites (=meadows) for all demographic descriptors were tested by a 3-way permutation-based ANOVA, including the factors: ‘Year’ (fixed factor), ‘Season’ (fixed factor and orthogonal to ‘Year’) and ‘Site’ (random factor orthogonal to both ‘Year’ and ‘Site’). Pairwise comparisons using permutations (Anderson, 2001) resolved differences between years for each site (significant ‘Year × Site’ interactions). Permutational Analysis of Variance uses permutations to calculate *P*-values. This was preferable because the data were over-dispersed and contained many zeros. In this sense, the Cochran's test was used to check for homogeneity of variances of each variable. However, no transformation rendered homogeneous variances for the biomass of *C. nodosa* and *C. prolifera* (Cochran's test, $p < 0.05$, for all type of transformations). The ANOVAs were then carried out on untransformed data, as it is robust to heterogeneity of variances for large balanced experiments (Underwood, 1997). To avoid an increase in a type I error rate, α values were then established at a conservative value of 0.01 (Underwood, 1997). Similarly, the significance of pairwise comparisons was fixed at the $\alpha = 0.01$ level. The test statistic (*pseudo-F*) is a multivariate analogue of the univariate Fisher's *F* ratio, and in the univariate context the two are identical when using Euclidean distance as the dissimilarity measure (Anderson, 2001).

2.2. Interaction between C. nodosa and C. prolifera: comparative field analysis

We sampled another 11 meadows (for a total of 16 meadows) in winter and summer of 2011 along the entire perimeter of Gran Canaria (Table 1), following the same criteria outlined previously. All these seagrass meadows were included in the shallow-water marine qualitative seagrass cartography of the island produced in 2002 and 2003 (Espino et al., 2003). A linear regression model tested whether the total biomass of *C. nodosa* and *C. prolifera* was significantly correlated at the island scale, i.e. including all 16 meadows, separately for winter and summer 2011, since both *C. nodosa* and *C. prolifera* show larger biomasses in summer than in winter in the Canary Islands (Reyes, 1993).

2.3. Interaction between C. nodosa and C. prolifera: experimental approach

We set up twelve 2 × 2 m plots on a mixed *C. nodosa* and *C. prolifera* meadow (‘*Gando Castillo*’, Table 1); adjacent plots were 2 m apart. Four plots were randomly assigned to each of 3 treatments: total (100%) removal of *C. prolifera* (ca. 140 ± 21 g DW m^{-2}), partial removal (50%, ca. 70 ± 9 g DW m^{-2}) and no removal (0%, procedural control) of *C. prolifera*. Removal was performed by SCUBA divers that carefully hand-picked stolons and blades of *C. prolifera*. An analogue disturbance, through flipping fins, but without actually removing *C. prolifera*, was conducted in control plots to avoid confounding results with manipulation artefacts. The experiment started on early March 2011 and lasted for 8 months; plots were visited every 5–6 weeks to maintain experimental treatments. At the end of the experimental period, two cores (20 cm of inner