CHAPTER 10

Cystoseira zosteroides

Laura Navarro[1], Bernat Hereu[2], Cristina Linares[2], Enric Ballesteros[1], Mikel Zabala[2], Chiara Bonaviri[3], Emma Cebrian[1] and Núria Teixidó[1]

[1]CEAB-CSIC; [2]Departament d'Ecologia, Univ. Barcelona; [3]Dipartimento di Ecologia, Univ. Palermo

Abstract

We evaluated the effects of an exceptional storm occurred along the Catalan coast on deep-water *Cystoseira zosteroides* populations in the coast of Montgrí and Medes Islands (NE Catalonia). The virulent storm affected differently *C. zosteroides* communities, with mortalities reaching in some locations 79% (this is amongst the highest ever recorded for perennial algae as a consequence of a single storm). We show that these deep-water, slow-growing *C. zosteroides* populations are driven by local processes and episodic catastrophic events, such as an exceptional storm, what can be determinant to understanding the structure and the long-term dynamics of these populations. These findings are of particular importance not only to fully understand the ecology of *Cystoseira zosteroides,* but also for its conservation.

Image: *Cystoseira zosteroides*, by Enric Ballesteros

Navarro, L., Hereu, B., Linares, C., Ballesteros, E., Zabala, M., Bonaviri, C., Cebrian, E., Teixidó, N. (2012) Spatial and temporal variability on deep-water assemblages of *Cystoseira zosteroides* C. Agardh (Fucales, Ochrophyta) in the Northwestern Mediterranean and the effects of an exceptional storm. In: Mateo, M.A. and Garcia-Rubies, T. (Eds.), Assessment of the ecological impact of the extreme storm of Sant Esteve's Day (26 December 2008) on the littoral ecosystems of the north Mediterranean Spanish coasts. Final Report (PIEC 200430E599). Centro de Estudios Avanzados de Blanes, Consejo Superior de Investigaciones Científicas, Blanes, pp. 135 - 146.

Proyecto Intramural Especial Cofinanciado CEAB-CSIC, PIEC 200430E599
FINAL REPORT, p. 135 – 146, April 2012

Spatial and temporal variability on deep-water assemblages of *Cystoseira zosteroides* C. Agardh (Fucales, Ochrophyta) in the Northwestern Mediterranean and the effects of an exceptional storm

By

Laura Navarro[1,2], Bernat Hereu[2], Cristina Linares[2], Enric Ballesteros[1], Mikel Zabala[2*] Chiara Bonaviri[3], Emma Cebrian[1] and Núria Teixidó[2]

[1]*Centre d'Estudis Avançats de Blanes- CSIC, Acc. Cala Sant Francesc 14, 17300 Blanes, Spain*
[2]*Departament d'Ecologia, Facultat de Biologia, Universitat de Barcelona, Diagonal 645, 08028 Barcelona, Spain*
[3]*Dipartimento di Ecologia Università di Palermo, via Archirafi 18, 90123 Palermo, Italy.*
*mzavala@ub.edu

Resumen

Hemos evaluado los efectos de una tormenta excepcional que barrió el norte de la costa Catalana sobre las poblaciones profundas de *Cystoseira zosteroides* en las costas del Montgrí y en las Illes Medes (NE Cataluña). La tormenta afectó de forma diferente a las comunidades de *C. zosteroides*, con mortalidades que llegaron al 79% en algunas localidades (mortalidad puntual de las mayores registrados hasta la fecha). Mostramos como las poblaciones profundas y de crecimiento lento de *C. zosteroides* podrían estar moduladas por procesos locales y por eventos catastróficos locales, como una tormenta extrema, pudiendo ser determinantes para entender la dinámica a largo plazo de estas poblaciones y para su conservación.

Abstract

We evaluated the effects of an exceptional storm occurred along the Catalan coast on deep-water *Cystoseira zosteroides* populations in the coast of Montgrí and Medes Islands (NE Catalonia). The storm affected differently *C. zosteroides* communities, with mortalities reaching in some locations 79% (this is amongst the highest ever recorded for perennial algae as a consequence of a single storm). We show that these deep-water, slow-growing *C. zosteroides* populations are driven by local processes and episodic catastrophic events, such as an exceptional storm, what can be determinant to understanding the structure and the long-term dynamics of these populations and for contributing to its conservation.

Introduction

The effect of low frequency exceptional storms on macroalgal population and assemblages has been documented as a driving force in determining algal assemblages at mid and long-term scales. High macroalgal mortality episodes have been described as a consequence of high intensity exceptional storms (e.g. Dayton and

Tegner, 1984; Dayton et al., 1989; Seymour et al., 1989; Graham et al., 1997). These high mortality events can lead to episodes of high recruitment thus changing the structure and also the dynamics of the community for several years (e.g.

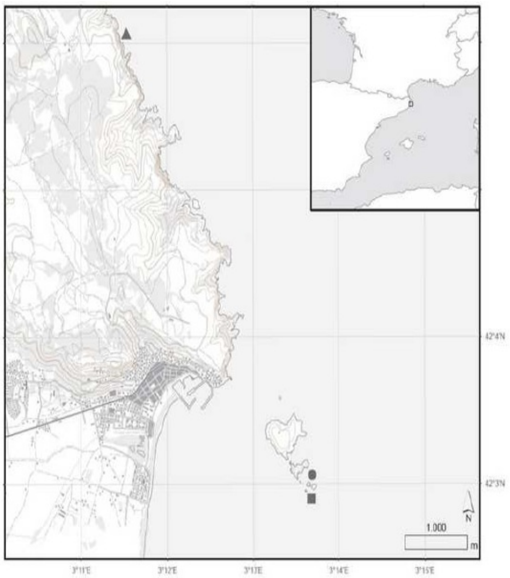

Fig. 1. Map of the study sites in Montgrí massif (▲ Tomas Ras) and Medes Islands Marine Reserve (● Ferranelles, ■ Tascons).

Deysher and Norton, 1982; Dayton and Tegner, 1984; De Wreede, 1984; Reed and Foster, 1984; Santelices and Ojeda, 1984; Kennelly, 1987; Dayton et al., 1992; Ballesteros et al., 1998)

In the Mediterranean Sea, some species of the genus *Cystoseira* C. Agardh (Fucales, Phaeophyceae) can dominate several rocky-bottoms assemblages (Giaccone, 1973), with some of them occurring in deep-water environments. These species are considered engineering species because their canopy provides complex biological structure, favouring the development of other associated species (Ballesteros, 1990; Ballesteros et al., 1998, 2009; Serio, 1994; Hereu et al., 2008), and thus they play a paramount role in the ecosystem functioning and structure (Ballesteros, 1992).

The Mediterranean endemic *Cystoseira zosteroides* dominates deep-water assemblages (Giacone, 1973), occurring on rocky bottoms exposed to strong unidirectional currents and with light levels ranging between 1% and 0.3% of surface irradiance, between 15m and 50m depth depending on the water clarity (Giaccone & Bruni, 1973).

Some studies describe small-scale patterns such as composition and population structure, revealing high diversity and a high spatial variability in the composition and structure of deep-water *Cystoseira* communities (Ballesteros, 1990; Serio, 1994; Hereu et al., 2008; Ballesteros et al., 2009). The only study on the long-term dynamics of C. zosteroides populations (Ballesteros et al., 2009) estimated very low growth rates (0.5 cm year^{-1}) and high longevity (more than 50 years) and suggested that populations of this species could be highly determined by large-scale, low frequency catastrophic episodic events. These unusual events would lead to punctual high mortality rates of large plants, clearing the canopy and, in turn, allowing intense pulses of recruitment. Similar dynamics have been hypothesized to occur in other algal assemblages (Schiel and Foster, 2006), although direct evidences are lacking.

Moreover, *C. zosteroides* it is among the most vulnerable species against anthropogenic disturbances such as mechanical losses, changes in water turbidity or competition with alien invasive species (Serio et al., 2006; Thibaut et al., 2005). Evidences exist that *Cystoseira zosteroides* assemblages are in decline in some Mediterranean areas, where their abundance and distribution has declined in the last years with dramatic effects at community level (Giaconne & Bruni, 1973; Thibaut et al., 2005; Serio et al., 2006). We fear that low-frequency natural disturbances such as extreme storms can put at the brink of extinction populations of *Cystoseira zosteroides* that are already decimated by anthropogenic disturbances.

In this study we describe the distribution, structure and dynamics of *Cystoseira zosteroides* populations in the coast of Montgrí (NW Mediterranean) by measuring population size structure, individual growth, mortality and recruitment. Moreover, we studied the effects of an exceptional storm occurred along the Catalan coast during the study period. By evaluating the effects of such low frequency events in determining the structure and dynamics of these populations, we get knowledge for understanding the processes that act at different scales in structuring these assemblages, which are of great importance for their conservation and management.

Materials and Methods

The study was carried out along the coastline of the Montgrí massif (NW Mediterranean), including the Medes Islands Marine Reserve, where *C. zosteroides* formed a canopy, two inside the Medes Islands Marine Reserve (Ferranelles and Tascons) and other one along the Montgrí coast (Tomas Ras) (Figure 1).

Ferranelles was located in a bottom dominated by small rocks and stones at 20 m depth in between two small islands, and exposed to the NW dominant winds in the area. Tascons assemblage was placed on a hard rocky bottom platform at 24 m depth exposed to E storms. Tomas Ras was located in the Montgrí coast, on a rocky bottom dominated by big boulders, and oriented to the N.

Permanent transects were installed in summer 2008 in the three sites in order to estimate recruitment, mortality and growth of individual plants at a long-term scale. At each site three transects within the same population were installed with permanent marks. Each transect was 1 m wide and 5 m in length or until reach a minimum of 50 individuals of *C. zosteroides*. Each transects was partitioned in a grid of 50 cm x 50 cm squares where each individual was mapped and length of the main axis measured following methodology explained in Ballesteros et al. (2009). Sampling was performed at the end of summer (August) when *Cystoseira* *zosteroides* attains its highest seasonal biomass (Ballesteros, 1990).

Transects were re-visited during summer 2009 in order to measure density and size structure after the winter storm and obtain the demographic rates (growth, mortality and recruitment) of the studied *C. zosteroides* populations.

Size-frequency distributions were compared between sites (2-sample Kolmogorov–Smirnov test) and to a normal distributions (single Kolmogorov–Smirnov test) using Lilleford probability adjustments (Legendre & Legendre, 1998). Similarity between size-frequency distributions was calculated with the Spearman rank-correlation coefficient by dividing plant numbers into 10 size classes (class borders were every 1 cm).

Differences between populations and years on frequency distribution and demographic parameters were compared using analysis of variance (ANOVA). Statistical analyses were performed using Systat 6.0 (SPSS Inc. 2004).

Results

The size-frequency distributions (Fig. 2) were unimodal, except for Ferranelles in 2009, and statistically different from a normal distribution (Table 1, $p < 0.05$). Ferranelles and Tascons displayed a similar size-frequency distribution and were statistically different to Tomas Ras (2-samples KolmogoroveSmirnov test, $p < 0.05$). Table 1 gives mean size, standard deviation, coefficient of variation, mode, 95th, skewness, kurtosis and the probability that the sample comes from a normal distribution calculated on raw data and the sample size for specific populations at each site before (2008) and after (2009) storm occurs. Depth, total sampling area and total adult and recruit densities for each site are also indicated. Distributions of Ferranelles and Tascons were similar and different from Tomas Ras. Nevertheless, other frequency distribution parameters showed differences between populations (Table 2).

Growth in surviving individuals ranged from 0.6 (Tascons), 0.75 (Tomas Ras) and 0.92 (Ferranelles) cm individual^{-1}. Mortality and recruitment were very different amongst populations. Mortality ranged from 78.5% in Ferranelles to 15% in Tascons, and recruitment from 3.7ind/0.25m2 in Ferranelles (83.45 %) to nil recruitment in Tomas Ras (0%). Adult and recruitment density as well as the general shape of the size frequency distribution and the distribution parameters (mean, skewness, kurtosis) significantly changed only in Ferranelles (2 samples Kolmogorov-Smirnov test, $p<0.05$).

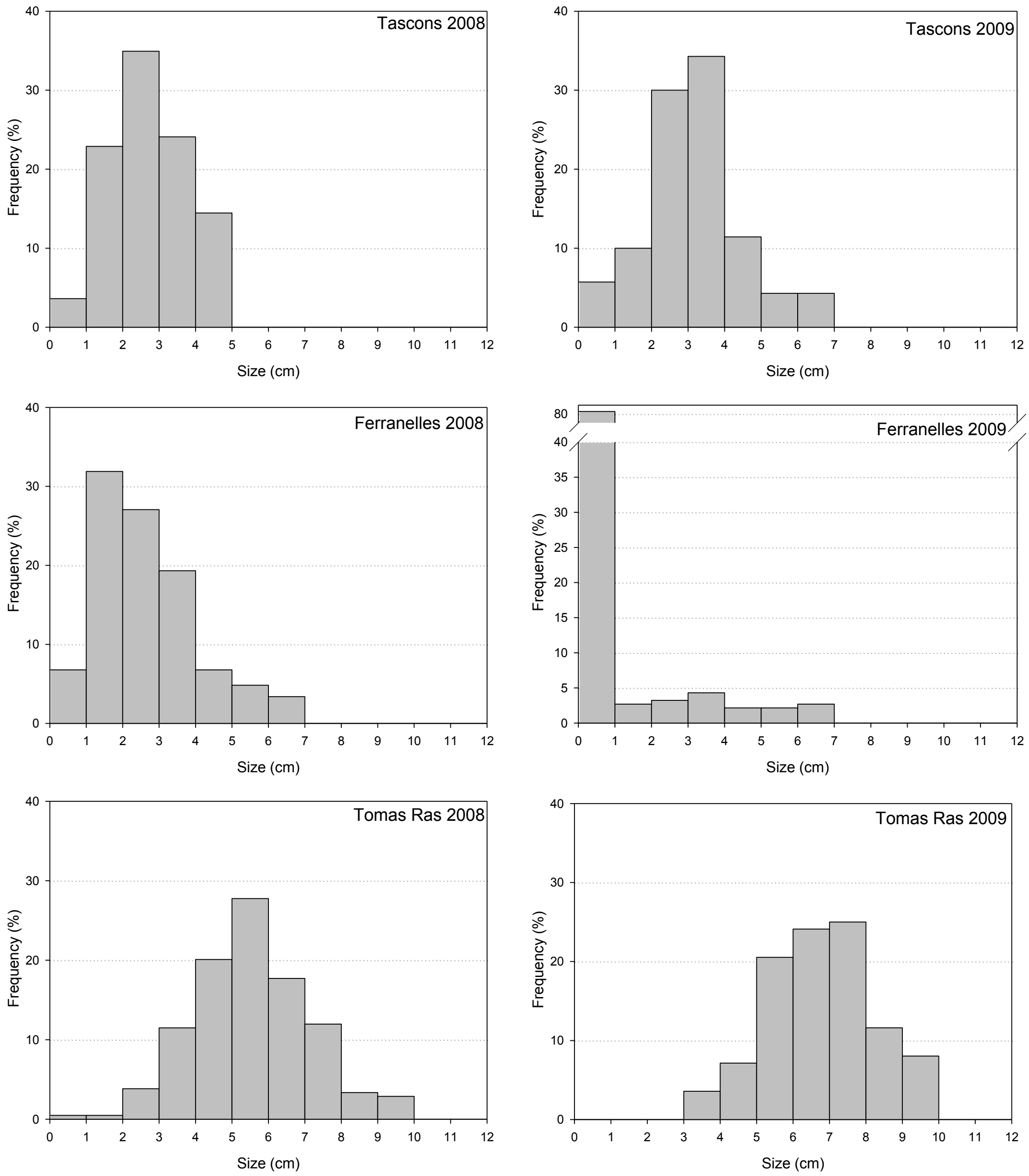

Figure 2. Size distribution frequencies of the length of the main axis of *Cystoseira zosteroides* in 2008 and 2009.

Conclusions

In Tomas Ras mortality accounted for roughly 50% of the population, but size distribution was maintained since recruitment was nil after the storm. Ferranelles displayed the highest mortality rates, probably because the storm dragged the small boulders and stones where the population thrives and eliminated more than 80% of the *C. zosteroides* individuals. However, recruitment was very high in 2009 resulting in a density increase in 2009, but a with completely different size distribution population.

Tascons population only displayed a 14% mortality, probably due to its deepest situation and the geomorphology of the bottom, devoid of boulders.

Mortalities described in this study are amongst the highest recorded for perennial algae as a consequence of a single storm (Dayton and Tegner, 1984; Ebeling et al., 1985; Seymour et al., 1989). Dayton and Tegner (1984) described up to a 60% mortality in a kelp forest. Nevertheless, due to the higher dispersal of spores and a faster growth of kelps (Schiel and Foster, 2006; Graham et al., 2007) the restoration of kelp forests should be much faster than these *Cystoseira* forests (Ballesteros et al. 1998, 2009).

We do not know the causes of the striking differences in recruitment rates among sites, but due to the relatively low reproductive potential and limited dispersal of fucoids with large propagules (Schiel and Foster, 2006) recruitment seems to be proportional to the abundance and proximity of adult stands.

Another reason could be the kind of substrate and the denso-dependent settlement and survival of recruits. For instance, boulders devoid of algal cover were available in Ferranelles due to the smashing effect of storm, thus allowing free space for *Cystoseira* propagules to settle. Contrarily, in Tomas Ras the bottom was still covered by encrusting corallines, filamentous understory algae and some adult individuals of *Cystoseira*, thus, being a substrate probably less favourable for recruits to settle and survive.

In conclusion, we have shown that these deep-water, slow-growing *C. zosteroides* populations are driven by local processes that account for the relatively high observed variability in processes such as growth, mortality and recruitment. Moreover, episodic catastrophic events such as an exceptional storm can be determinant in understanding the structure and the long-term dynamics of these populations. However, even these catastrophic events have a large variability at small scales due to factors such as wave exposure or bottom morphology. The combination of this short-term acting factors that ensure long periods of steady growth with episodic disturbances that can determine populations at long temporal scale together with the variability associated to these factors, should be responsible for the complex, almost unpredictable, distribution and size structure of these deep water *Cystoseira* stands. Similar findings have been described for other algal-dominated ecosystems, such as kelp forests, that are exposed to a large array of small-scale processes and disturbances, but also to a large-scale, low-frequency episodic disturbances (e.g. storms, nutrient pulses, temperature anomalies) which can finally determine the shape of these algal populations and the whole assemblage (Dayton et al., 1992, 1999; Tegner et al., 1996, 1997; Graham et al., 2007).

These findings are of particular importance not only to fully understand the ecology of *Cystoseira zosteroides*, but also for its conservation. Deep water *Cystoseira* assemblages are largely endangered by anthropogenic impacts (Boudouresque et al. 1990, Thibaut et al. 2005) and stochastic low-frequency processes could explain the sudden disappearance of these deep water stands in areas without apparently significant anthropogenic impacts (e.g. Cormaci & Furnari, 1999; Alongi et al. 2004). Otherwise, these episodic disturbances can act synergystically with the punctual small-scale anthropogenic disturbances to put at the brink of extinction of these highly structured, slow-growing and highly biodiverse deep algal assemblages. So, these results reinforce the importance of reducing, as far as possible, any source of human disturbance to conserve these threatened communities.

Acknowledgements

The PADI Foundation funded part of this study. We would like to thank also Josep Pascual for providing meteorological data.

The authors are grateful to CSIC for funding the general framework project "Assessment of the ecological impact of the extreme storm of Sant Esteve (26 December 2008) on the littoral ecosystems of the north Mediterranean Spanish coasts" (PIEC 200430E599).

References cited

Alongi, G., Catra, M., Cormaci, M., Furnari, G., Serio, D., 2004. Spring marine vegetation on rocky substrata of Pantelleria Island (the Straits of Sicily, Italy). Nova Hedwigia 79, 447–478.

Ballesteros, E., 1990. Structure and dynamics of the assemblage of Cystoseira zosteroides (Turner) C. Agardh (Fucales, Phaeophyceae) in the Northwestern Mediterranean. Scientia Marina 54, 217–229.

Ballesteros, E., Sala, E., Garrabou, J., Zabala, M., 1998. Community structure and frond size distribution of a deep water stand of Cystoseira spinosa (Phaeophyta) in the northwestern Mediterranean. European Journal of Phycology 33, 121–128.

Ballesteros, E., Garrabou, J., Hereu, B., Zabala M., Cebrian, E., Sala E., 2009. Deep-water stands of Cystoseira zosteroides C. Agardh (Fucales, Ochrophyta) in the Northwestern Mediterranean: Insights into assemblage structure and population dynamics. Estuarine, Coastal and Shelf Science 82, 477–484.

Dayton, P.K., Tegner, M.J., 1984. Catastrophic storms, El Niño and patch stability in a California kelp community. Science 224, 283–285.

Boudouresque, C.F., Meinesz, A., Ballesteros, E., Ben Maiz, N., Boisset, F., Cinelli, F., Cirik, S., Cormaci, M., Jeudy de Grissac, A., Laborel, J., Lanfranco, E., Lundberg, B., Mayhoub, H., Panayotidis, P., Semroud, R., Sinnasamy, J.M., Span, A., 1990. Livre Rouge ''Gérard Vuignier'' des végétaux, peuplements et paysages marins menacés de Méditerranée. MAP Technical Report Series 43. UNEP/IUCN/GIS Posidonie, Athens, 245 pp.

Cormaci, M., Furnari, G., 1999. Changes of the benthic algal flora of the Tremiti Islands (Southern Adriatic) Italy. Hydrobiologia 399, 75–79.

Dayton, P.K., Seymour, R.J., Parnell, P.E., Tegner, M.J., 1989. Unusual marine erosion in San Diego County from a single storm. Estuarine, Coastal andShelf Science 29, 151–160.

Dayton, P.K., Tegner, M.J., Parnell, P.E., Edwards, P.B., 1992. Temporal and spatial patterns of disturbance and recovery in a kelp forest community.

Ecological Monographs 62, 421–445. Deysher, L., Norton, T.A., 1982. Dispersal and colonization in Sargassum muticum (Yendo) Fensholt. Journal of Experimental Marine Biology and Ecology 56,179–195.

De Wreede, R.E., 1984. Growth and age class distribution of Pterygophora californica (Phaeophyta). Marine Ecology Progress Series 19, 93–100.

Giaccone, G., 1973. Écologie et chorologie des Cystoseira de Méditerranée.Rapports Communications Internationales Mer Méditerranéenne 22, 49–50.

Giaccone, G., Bruni, A., 1973. Le cistoseire e la vegetazione sommersa del Mediterraneo. Atti Istituto Veneto Scienze, Lettere e Arti 131, 59–103.

Graham, M.H., Harrold, C., Lisin, S., Light, K., Watanabe, J.M., Foster, M.S., 1997. Population dynamics of giant kelp, Macrocystis pyrifera, along a wave exposure gradient. Marine Ecology Progress Series 148, 269-279.

Hereu, B., Mangialajo, L., Ballesteros, E., Thibaut, T., 2008. On the occurrence, structure and distribution of deep-water Cystoseira populations in the Port-Cros National Park (North-western Mediterranean). European Journal of Phycology 43, 263–273.

Kennelly, S.J., 1987. Inhibition of kelp recruitment by turfing algae and consequences for an Australian kelp community. Journal of Experimental Marine Biology and Ecology 112, 49–60.

Legendre, P., Legendre, L., 1998. Numerical Ecology (2nd English Edition). Elsevier, Amsterdam, The Netherlands.

Reed, D.C., Foster, M.S., 1984. The effects of canopy shading on algal recruitment and growth in a giant kelp (Macrocystis pyrifera) forest. Ecology 65, 937–948.

Santelices, B., Ojeda, F.P., 1984. Recruitment, growth and survival of Lessonianigrescens (Phaeophyta) at various tidal levels in exposed habitats of Central Chile. Marine Ecology Progress Series 19, 73–82.

Schiel, D., Foster, M., 2006. The population biology of large brown seaweeds: ecological consequences of multiphase life histories in dynamic coastalenvironments. Annual Review of Ecology and Systematics 37, 343-72.

Serio, D., 1994. On the structure, typology and periodism of Cystoseira spinosa Sauvageau community and of Cystoseira zosteroides C. Agardh community from Eastern Coast of Sicily. Giornale Botanico Italiano 128, 941–973.

Serio, D., Alongi, G., Catra, M., Cormaci, M., Furnari, G., 2006. Changes in the benthic algal flora of Linosa Island (Straits of Sicily, Mediterranean Sea). Botanica Marina 49, 135–144.

Seymour, R.J., Tegner, M.J., Dayton, P.K., Parnell, P.E., 1989. Storm wave induced mortality of giant kelp, Macrocystis pyrifera, in Southern California. Estuarine, Coastal and Shelf Science 28,277-292.

Tegner, M.J., Dayton, P.K., Edwards, P.B., Riser, K.L., 1996. Is there evidence for long-term climatic change in southern California kelp forests? CalCofi Reports 37, 111–126.

Tegner, M.J., Dayton, P.K., Edwards, P.B., Riser, K.L., 1997. Large-scale, lowfrequency oceanographic effects on kelp forest succession: a tale of two cohorts. Marine Ecology Progress Series 146, 117–134.

Thibaut, T., Pinedo, S., Torras, X., Ballesteros, E., 2005. Long-term decline of the populations of Fucales (Cystoseira spp. and Sargassum spp.) in the Albères coast (France, Northwestern Mediterranean). Marine Pollution Bulletin 50, 1472–1489.

Table 1. Distribution parameters of raw plant size data for *Cystoseira zosteroides* at 3 sites (T: Tascons; F: Ferranelles; TR: Tomas Ras). ρ: density (total, adults and recruits) (ind/0.25m²). Mean: mean plant size; SD: Standard Deviation; V: Coefficient of Variation; 95%: 95th percentile; g_1: skewness; g_2: kurtosis; d: Kolmogorov-Smirnov *d* statistic; p_{norm}: probability that data are from normal distribution (Kolmogorov-Smirnov test using Lillefor adjusted probability); n: total number of plants measured.

Year	Site	Depth (m)	Area (m²)	ρ total	ρ ad	ρ recr	Mean (cm)	SD (cm)	V	Mode	95%	g_1	g_2	d	p_{nom}	n
2008	T	25	17	0.79	0.76	0.03	2.46	0.20	41.58	2.33	4.5	0.13	-0.69	0.14	**<0.01**	83
2008	F	20	10	4.52	4.25	0.27	2.44	0.18	56.21	1.67	5	0.96	0.97	**0.14**	**<0.01**	182
2008	TR	20	16.5	3.16	3.15	0.01	6.27	0.20	25.70	5.67	9	0.11	0.06	**0.09**	**<0.01**	209
2009	T	25	17	0.65	0.62	0.03	2.94	0.26	43.11	2.50	5	0.33	0.54	0.11	**<0.05**	70
2009	F	20	10	4.48	0.78	3.69	0.98	0.17	129.15	0.50	4	3.05	9.39	**0.47**	**<0.01**	186
2009	TR	20	16.5	1.73	1.70	0.03	6.23	0.27	22.62	6.00	9	-0.05	-0.34	**0.12**	**<0.01**	114

Table 2. Similarity between size-specific distribution of the different sites (Spearman-rank correlation coefficient calculated on 10 size classes based on logarithmic scale) (* statistically significant).

	Tascons 2008	Tomas Ras 2008	Ferranelles 2008	Tascons 2009	Tomas Ras 2009
Tascons 2008	-				
Tomas Ras 2008	-0.16	-			
Ferranelles 2008	* 0.93	-0.21	-		
Tascons 2009	* 0.96	-0.07	* 0.94	-	
Tomas Ras 2009	-0.35	* 0.95	-0.33	-0.25	-
Ferranelles 2009	* 0.86	-0.15	* 0.89	* 0.91	-0.35