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Evolution of *Posidonia oceanica* seagrass meadows and its implications for management☆

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ABSTRACT

Results of the monitoring network of the *Posidonia oceanica* meadows in the Valencia region in Spain are analysed. For spatial comparison the whole data set has been analysed, however, for temporal trends we only selected stations that have been monitored at least 6 years in the period of 2002–2011 (26 stations in 13 localities). At the south of the studied area, meadows are larger, and they have higher density and covering than that in the Valencia Gulf, excluding Oropesa meadow. Monitoring of *P. oceanica* meadows in the Valencia region in Spain indicates that most of them are stationary or they are increasing their density and covering while no decline was observed in the studied meadows. These results indicate that there is not a general decline of *P. oceanica* meadows and that the decline of *P. oceanica*, when it has been observed in other studies, is produced by local causes that may be managed at the local level. This study also reflects the importance of long series of direct data to analyse trends in the population dynamics for slow-growing species.

1. Introduction

Seagrasses support marine food webs and provide essential habitat for many coastal species, playing a critical role in the equilibrium of coastal ecosystems and human livelihoods (Short et al., 2011). A wide range of population dynamics strategies is found in seagrasses from small, fast-growing, pioneer species to large, slow-growing, climax species (Marbà and Duarte, 1998). *Posidonia oceanica* is a slow-growing species endemic of the Mediterranean Sea, where it is the dominant seagrass. Several studies have indicated that seagrass habitat is declining worldwide (Short et al., 2011; Waycott et al., 2009). In the Mediterranean, *P. oceanica* decline has been proved in response to human impacts that produce changes in water quality (Cancemi et al., 2003; Delgado et al., 1997, 1999; Dimech et al., 2000; Ruíz et al., 2001); mechanical erosion (Francour et al., 1999; García Charton et al., 1993; Martín et al., 1997; Milazzo et al., 2004; Sánchez Lizaso et al., 1990, 2002); or burial (Fernández Torquemada et al., 2005; González Correa et al., 2008, 2009; Manzanera et al., 1998). However, while some authors think that a global process of decline is occurring (Jorda et al., 2012; Pérès, 1984), other studies show that the decline is due to an accumulation of local impacts (González Correa et al., 2007a). This aspect is relevant for seagrass management, since it is possible to act upon these local causes that produce local decline (González Correa et al., 2005; Pergent-Martini et al., 2002) but a global degradation caused by global processes could not be stopped by management of coastal areas and even if it were possible, the time needed to solve the problem would exceed human time scales (González Correa et al., 2005).

For slow-growing species like *P. oceanica*, population dynamics is mainly based on reconstructive techniques or direct measurements over a few numbers of years. While some reconstructive techniques are biased (González Correa et al., 2007b), the extrapolation of trends obtained over short time periods may also give an incorrect pattern. In order to establish evolution of *P. oceanica* meadows, monitoring networks have been established in different regions of the Mediterranean (Lopez y Royo et al., 2010; Sánchez Lizaso, 2009). In this paper, we used the results of the monitoring network of the *P. oceanica* meadows in the Valencia region in Spain in the period of 2002–2011 to analyse the evolution of the meadows in the warmest part of Western Mediterranean, since it may be useful to detect if a global decline is occurring.

2. Material and methods

Monitoring of *P. oceanica* meadows in the Valencia region commenced in 2002 and it was done on an annual basis on up to 24 localities. However, the monitoring period is different at each locality. Table 1 indicates the available data for each locality. Monitoring has been done during summer months each year. Monitoring was carried out by volunteers

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Table 1
Monitoring years at each locality.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Alcossebre		X								
Oropesa						X	X	X		
Castellón			X							
Moncofar				X	X					
Canet			X			X	X	X		
El Puig		X	X	X						
Cullera				X						
Denia	X	X		X	X	X	X	X		
Javea						X	X	X	X	X
Moraira	X	X	X	X	X	X	X	X		
Calpe	X	X	X	X	X	X	X	X	X	X
Altea	X	X	X	X	X	X	X	X	X	X
Cala Mina			X	X	X	X	X	X	X	X
Benidorm	X	X	X	X	X	X	X	X	X	X
Racó Conill			X	X			X	X	X	X
Paradís	X	X	X		X	X				
El Campello	X	X	X	X		X	X	X		X
Cabo Huertas	X	X	X	X	X	X	X		X	X
Postiguet Coco	X									
Postiguet	X	X	X	X	X	X	X	X	X	X
Carabassí		X	X	X	X	X	X	X	X	X
Tabarca La Nao	X	X	X	X	X	X	X	X	X	X
Tabarca Escull Negre	X	X	X	X	X	X	X	X	X	X
Torrevieja	X	X	X	X	X	X	X	X		

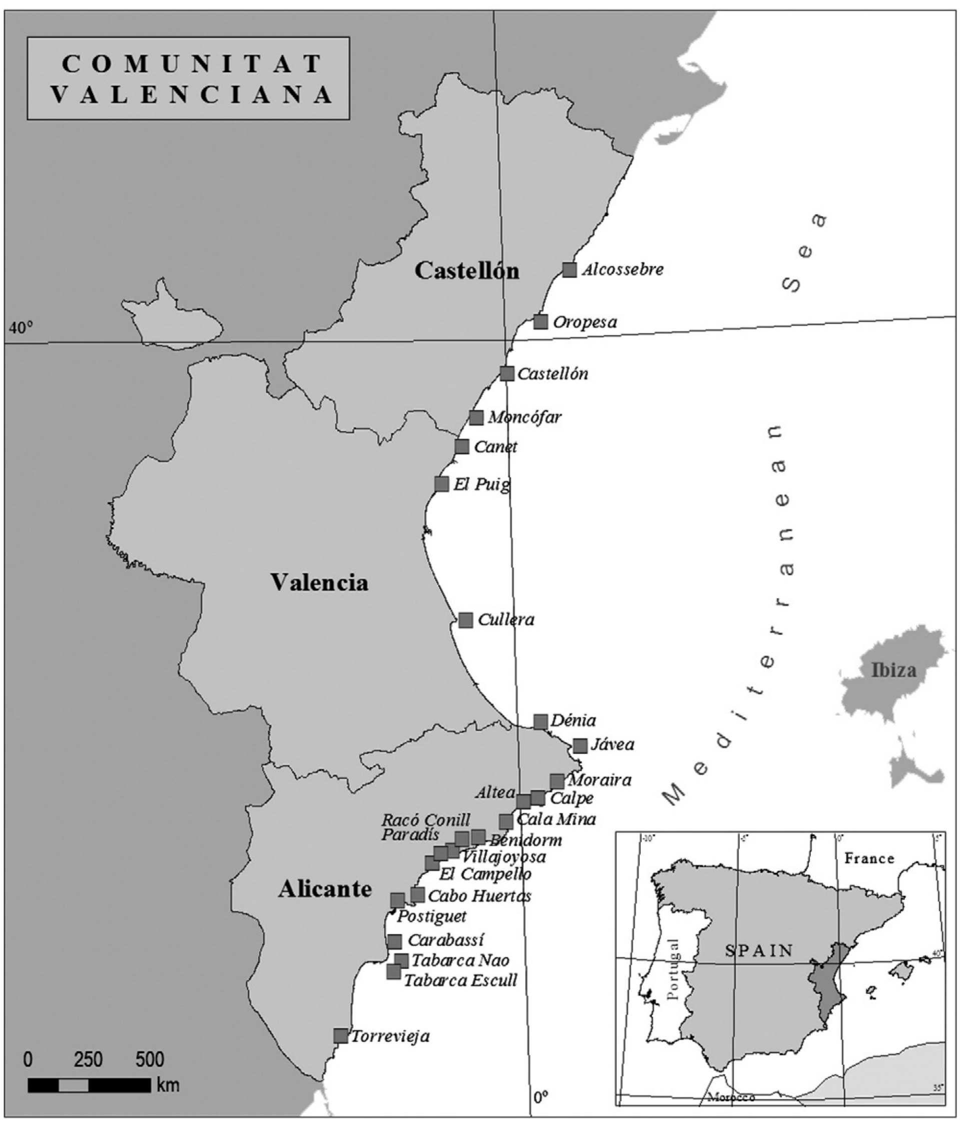

Fig. 1. Situation of studied localities.

after scientific training and always under the supervision of a researcher to ensure the quality of the data (Codina et al., 2009). When possible, two stations were established at each locality: "shallow" between 5 and 8 m depth; and "deep" between 12 and 17 m. The selected main descriptors were density (shoots/m^2) that was estimated with 9 replicates of a 40×40 cm square and covering with 6 random replicates of a transect of 25 m assuming that the linear distance of the transect inside *Posidonia* patches is proportional to the surface covered by the meadow in percentage of the sea bottom (Sánchez Lizaso, 1993). With these two descriptors we estimate global density as the result of multiplying the average density inside *P. oceanica* patches by the proportion covered by the meadow (Lopez y Royo et al., 2010; Romero, 1989). For spatial comparison, we used the whole data set; whilst to analyse temporal trends, we only selected the stations that have been monitored for more than 5 years.

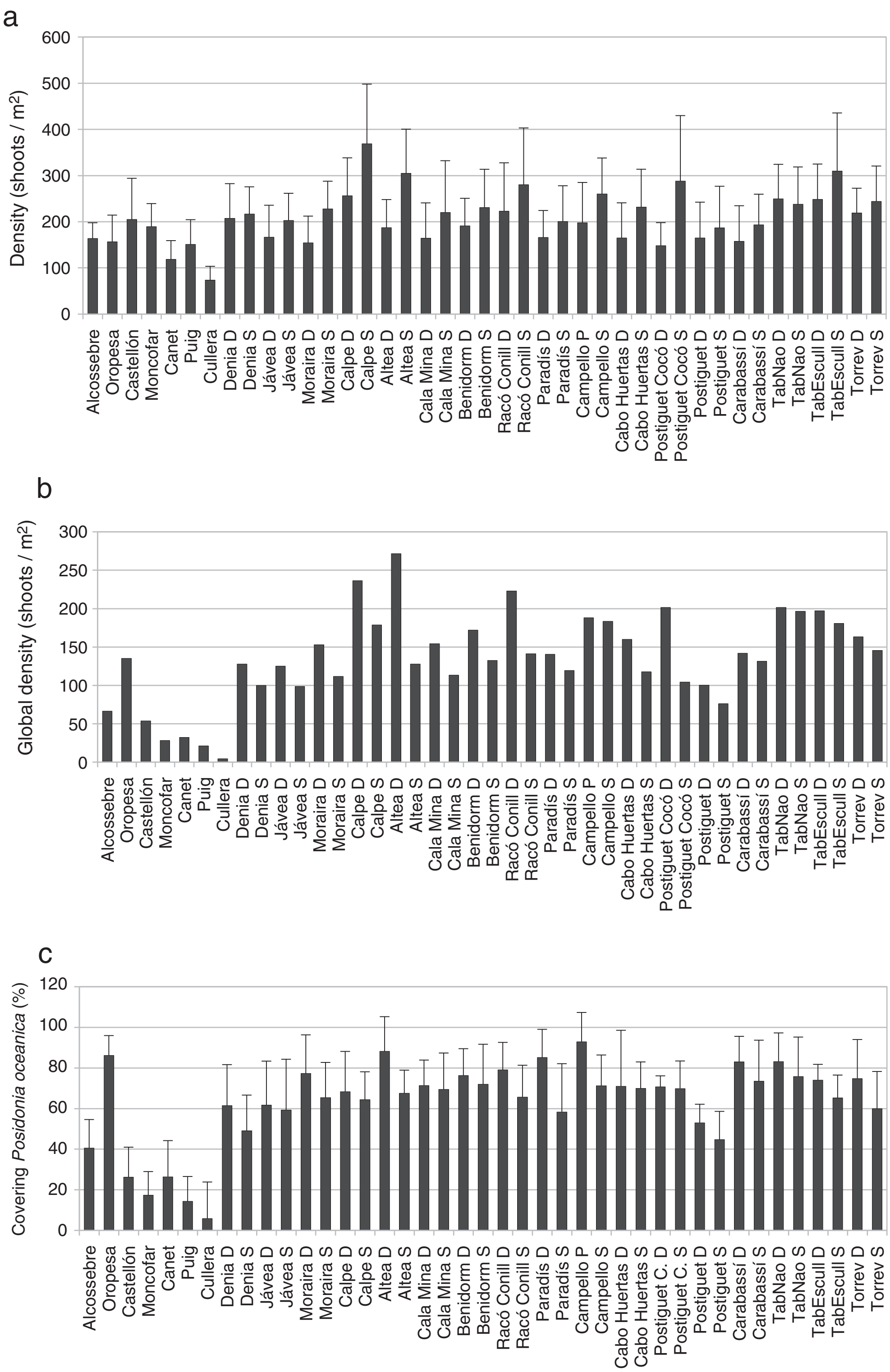

Fig. 2. Average values in the period of 2001–2011 at all the studied localities for: a, density; b, global density; and c, covering. Error bars indicate standard deviation. S and D indicate shallow and deep stations respectively.

Table 2
Trends of *Posidonia oceanica* density, covering and global density at each station. (+) increasing trend with time, (−) decreasing trend with time (**) $p < 0.05$, (*) $0.05 < p < 0.1$.

Station	Density		Covering		Global density	
	Slope	p-Value	Slope	p-Value	Slope	p-Value
Denia D	+	*	−		+	
Denia S	+	**	−		+	**
Moraira D	+		+	**	+	
Moraira S	+		+		+	**
Calpe D	+		+	**	+	
Calpe S	+		+	**	+	*
Altea D	−		+	*	+	
Altea S	+		+	**	+	**
Cala Mina D	+		+	**	+	**
Cala Mina S	−		+		−	
Benidorm D	+	**	+		+	**
Benidorm S	+	**	+		+	**
Raco Conill D	+		+		+	*
Raco Conill S	+	**	−		+	**
Campello D	+		−	**	+	
Campello S	+	**	+	*	+	**
Cabo Huertas D	−		−	*	−	
Cabo Huertas S	+	**	−		+	**
Carabassi D	+	**	+	**	+	**
Carabassi S	+		+		+	
TabNao D	+		+		+	**
TabNao S	+	**	+		+	**
TabEscull D	+	**	+		+	**
TabEscull S	+	**	+		+	**
Torrevieja D	−		+		−	
Torrevieja S	+	**	+	**	+	**

Fig. 1 indicates the position of the studied localities. Linear regression models have been used to look for significant changes over time. We used a significance value of 0.05 but we also included as marginally significant p values between 0.05 and 0.1 since, in this case, it is justified to increase the probability of type I error and to reduce the probability of type II error (Fairweather, 1991).

3. Results

Average density ranges from 73 to 369 shoots/m^2 and average global density ranges between 4 and 272 shoots/m^2. Southern localities present higher values than northern ones (Oropesa, Cullera, Moncofar, Canet, Alcossebre and Puig) both for density and global density (Fig. 2a, c). Covering is also lower in northern stations, where it is always under 50%, excluding Oropesa meadow (Fig. 2c).

When analysing trends of density covering and global density, a significant increase or stability (i.e. no significant trend) are the most common patterns observed. We also observed only 3 or 4 non-significant negative trends for global density and density respectively, while there are 7–10 non-significant positive trends and 16–12 significant positive trends (including marginally significant trends with p between 0.05 and 0.1) in global density and density respectively (Table 2, Figs. 3 and 4). Significant increases of global density are obtained both at shallow and deep meadows, but they are more common in shallower stations (10 shallow and 6 deep stations). When analysing covering data, a significant decline is observed in only one station (El Campello deep) and another marginally significant negative trend (Cabo de Huertas deep) and 4 non-significant negative trends in front of 9 significant and 11 non-significant positive trends (Fig. 5, Table 2).

When analysing data from all stations and years together, it has been observed that density of *P. oceanica* meadows is significantly higher when increasing the covering of rock (Fig. 6a) and has a negative but non-significant trend with the covering of dead *Posidonia* (Fig. 6b), however, the variability is very high.

4. Discussion

Monitoring of *P. oceanica* meadows in the Valencia region in Spain indicates that most of them are stationary or they are increasing their density and covering while almost no significant decline has been observed in the studied meadows in the past years. We only observed a significant declining trend in covering in two stations but this trend is not significant for density and global density in these meadows. These results concur with what has been observed by González Correa et al. (2007a) where no decline was found in several meadows placed in marine protected areas around the Mediterranean Sea. Terrados and Medina-Pons (2011) also found a significant increase of density in two *P. oceanica* meadows monitored during 6 years at the Balearic Islands. However, these results are in contrast with some studies that have found the opposite pattern, suggesting that *P. oceanica* shows evidence

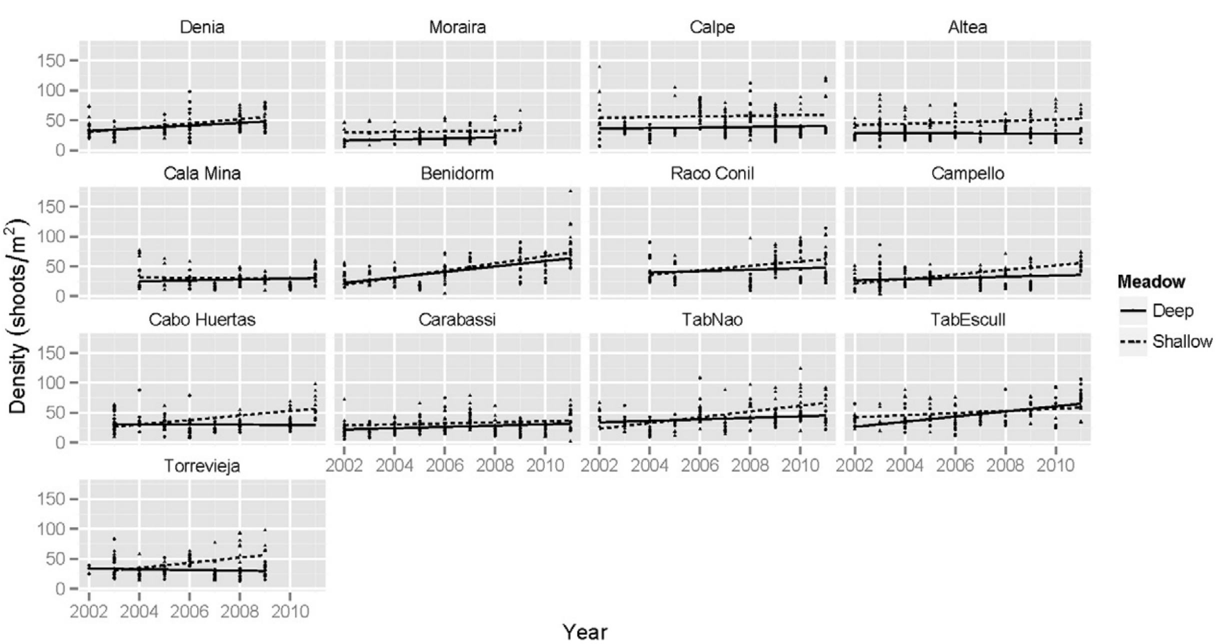

Fig. 3. Trends of density in the period of 2002–2011 at each locality for shallow and deep meadows.

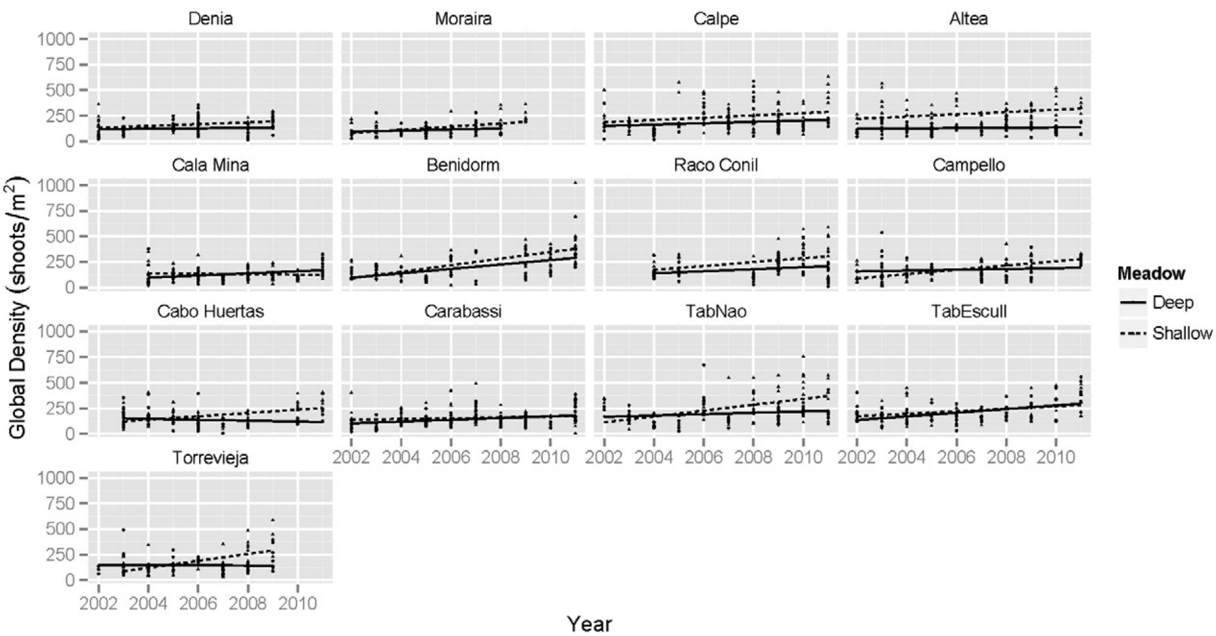

Fig. 4. Trends of global density in the period of 2002–2011 at each locality for shallow and deep meadows.

of decline on a global scale (Jorda et al., 2012; Short et al., 2011; Waycott et al., 2009).

A retrospective demographic analysis, using reconstructive techniques of 27 *P. oceanica* meadows on the Spanish coast, showed that 80% of them were declining between 1967 and 1992 (Marbà et al., 1996). Marbà et al. (2002) found that, also using reconstructive techniques, mortality exceeds recruitment in 55% of the meadows studied in a marine protected area in Spain. Moreover, Marbà (2009), using permanent plots quantifying the annual demographic balance in 46 *P. oceanica* meadows, found that in 67% of the meadows studied, net losses of shoot density, exceeding 20% in 47% of cases, were observed. Marbà (2009) estimates shoot mortality rates varying between less than 1% year^{-1} and 84% year^{-1}, equivalent to absolute shoot mortality rates between 4 and 320 dead shoots m^{-2} year^{-1}. Based on these results, a rate of decline of *P. oceanica* meadows has been estimated of 5% per year (Marbà, 2009; Short et al., 2011) and that these decline rates have been similar during the last four decades (Marbà, 2009). Our results do not support this pattern and it has to be considered that, if this decline rate has been constant during the last 40 years, most Spanish meadows will have disappeared or, at the very least, they will have very low densities at the present time, which is not consistent with our field data.

These striking differences may be related to the different techniques that have been used in each study. It has been observed that some reconstructive techniques, such as that based in age structure, may overestimate mortality and underestimate the recruitment of *Posidonia oceanica* shoots and produce an unreal declining trend (González Correa et al., 2007b). Conversely, permanent plots and shoot marks

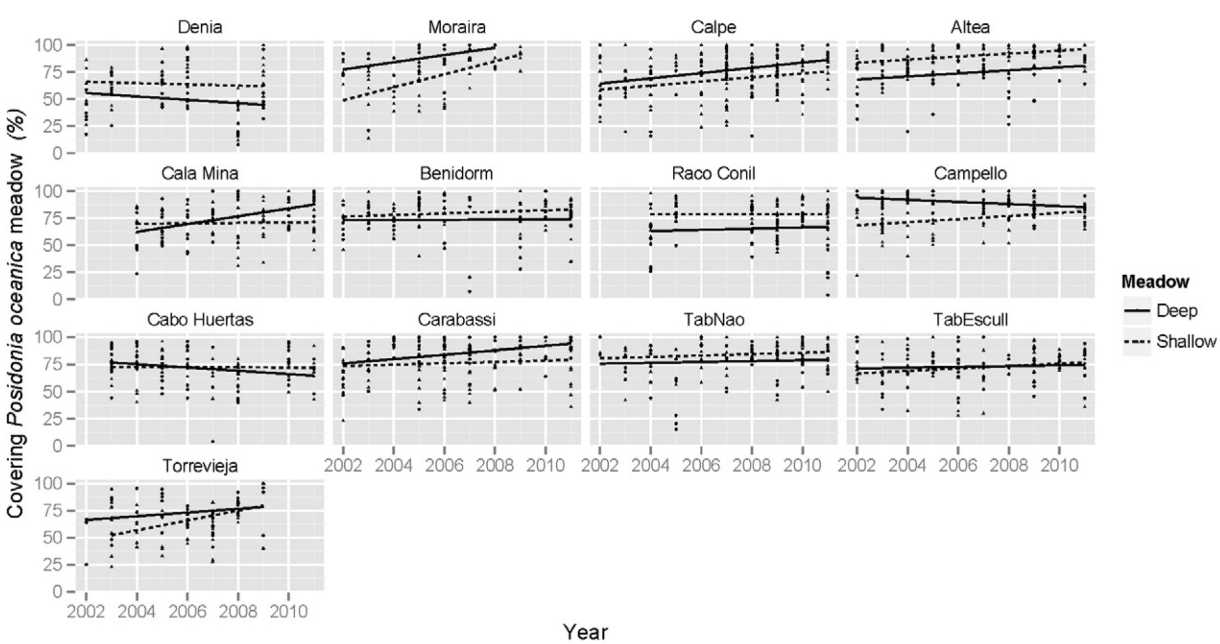

Fig. 5. Trends of meadow covering in the period of 2002–2011 at each locality for shallow and deep meadows.

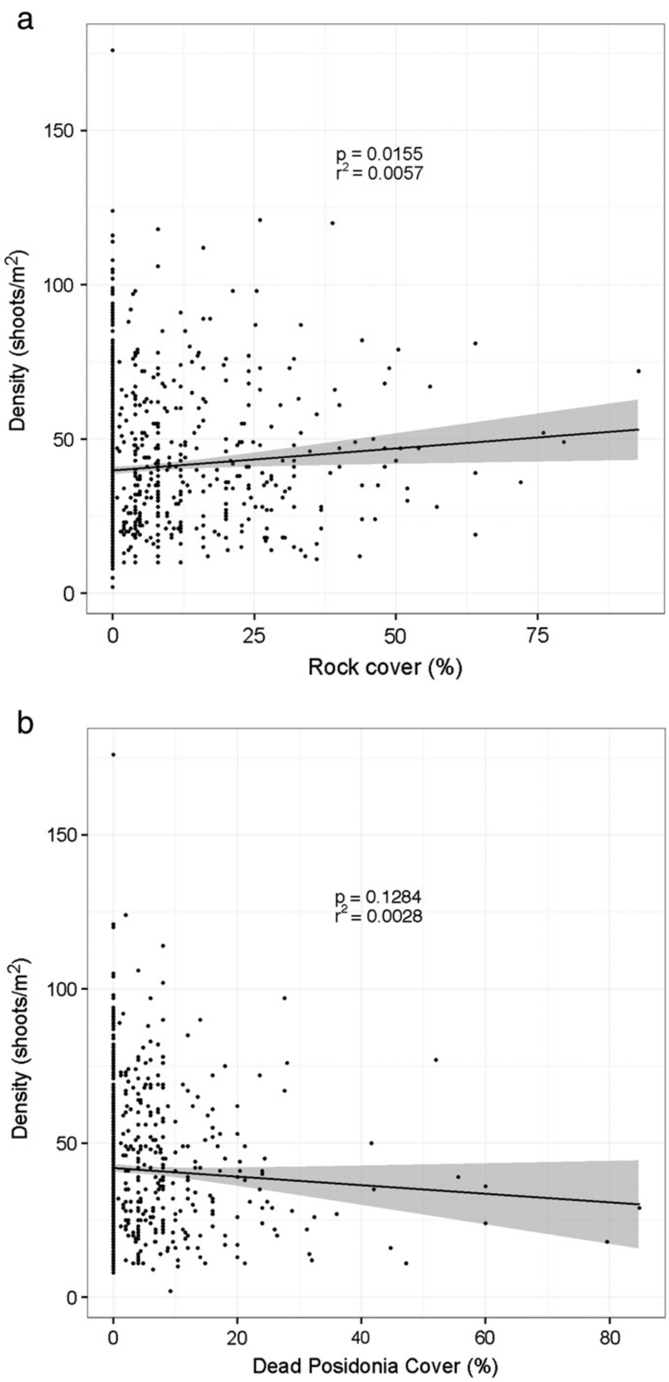

Fig. 6. Relation between density of studied meadows and a) cover of rock and b) cover of dead *Posidonia*.

may increase shoot mortality and it seems more realistic to use repeated density counting in the same location that results in less impact on the plants, or at least to do it as an artefact control to be sure that mortality is not increased by shoot manipulation.

On the other hand, an important effort has been made in the last years in reducing impacts that produce the decline of *P. oceanica* meadows in Spain and other Mediterranean countries (Boudouresque et al., 2009). One of the most important causes of decline up to 20 years ago was the impact of trawling (Sánchez Lizaso et al., 1990). It has been estimated that 42 km^2 of 212 km^2 studied in the Alicante area (20% of the surface of the meadows, mainly deep meadows) are in regression due to otter trawling (Sánchez Lizaso et al., 2002). The decline of deep meadows due to otter trawling has been drastically reduced in this area due to the deployment of anti-trawling reefs (Guillén et al., 1994) and the better surveillance that includes Vessel Monitoring Systems (VMS) for all the boats longer than 12 m, together with the use of helicopters that are much faster than boats previously used for enforcement. As a result of protection of the meadows with anti-trawling reefs, a recovery of previously impacted meadow was observed (González Correa et al., 2005). Land reclamation, including marinas and artificial beaches, has also produced the decline of shallow meadows (Fernández Torquemada et al., 2005; González Correa et al., 2008, 2009), but the protection of the meadows has reduced the number of these projects near *Posidonia* beds. Eutrophication from sewage or aquaculture in the past has also been an important source of decline of the meadows (Cancemi et al., 2003; Delgado et al., 1997, 1999; Dimech et al., 2000; Ruíz et al., 2001).

Aquaculture impact has been reduced with offshore aquaculture if it is far enough from the limits of the *Posidonia* meadows (Ruiz et al., 2010) and with a more efficient feeding. Conversely, the impact of sewage may be reduced; improving the water treatment and favouring water reuse (Del Pilar Ruso et al., 2010; Pergent-Martini et al., 2002). Anchoring impacts that also may produce the decline of the meadows may be reduced avoiding the mooring on the meadows or the adoption of seagrass-friendly mooring technology (Montefalcone et al., 2008).

To prevent new potential impacts such as desalination, previous studies have been conducted to establish secure threshold limits of tolerance for *P. oceanica* meadows (Fernández Torquemada and Sánchez Lizaso, 2005; Gacia et al., 2007; Sánchez Lizaso et al., 2008) and the brine discharge has been modified to reduce impacts on the meadows (Malfeito et al., 2005).

These results show that the decline of *P. oceanica* meadows is mainly produced by local impacts that could be reduced with an appropriate management. However, it is important to expand the monitoring of seagrass meadows (Sánchez Lizaso, 2009) to detect any early decline symptom in order to act, as soon as possible, against the observed causes of decline because, when a regression of *the P. oceanica* beds is produced, it could not be recovered at human scales (González Correa et al., 2005).

5. Conclusions

Monitoring of *P. oceanica* meadows at 13 localities in the Valencia region in Spain indicates that most of them are stationary or they are increasing their density and covering while no decline was observed in the studied meadows.

These results indicate that there is not a general decline of *Posidonia oceanica* meadows and that the decline of *P. oceanica*, when it has been observed in other studies, is produced by local causes that may be managed at the local level.

This study reflects also the importance of long series of direct data to analyse trends in the population dynamics for slow-growing species.

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