Rocky Bottom Communities

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Abstract

We quantified multiple times before and after the storm the benthic and fish communities at 12 locations scattered over a distance of 50 km in the north of the Costa Brava. The storm caused no differences on the functional richness, evenness, or diversity but led to significant changes in community organization. The benthic percent cover of bare rock and hydrozoans significantly increased after the storm, most likely at the expenses of foliose algae. Our data suggest that this unprecedented storm simply wiped out a small percentage of erect algae and generated additional free space that were used by a number of species, changing the organization of the community but causing no significant impact on the functional traits of the ecosystem. Despite major damage in specific locations, our data also suggest that Mediterranean shallow rocky communities are resistant to the disturbance caused by severe storms.

Image: A shallow rocky community in Callella de Palafrugell, Costa Brava. By Miguel A. Mateo

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A freak storm in the spotlight: the significant petty effects of a once-in-50-years storm on shallow rocky communities

By

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Resumen

Hemos cuantificado en varias ocasiones antes y después de la tormenta las comunidades bentónicas y de peces en 12 localidades en el norte de la Costa Brava y en otras 126 a lo largo del resto de la costa catalana. La tormenta no provocó cambios en la riqueza funcional o en la diversidad pero produjo cambios en la organización de la comunidad en la Costa Brava. Aquí, el porcentaje de roca desnuda y de hidrozoos aumentó significativamente tras la tormenta, muy posiblemente debido al denudado de algas frondosas. Los datos sugieren que la tormenta barrió una pequeña proporción de la cobertura algal en esta zona generando espacio disponible para otras especies, cambiando la organización de la comunidad pero no los rasgos funcionales del ecosistema. En el resto de la costa, a falta de un análisis de los datos más exhaustivo, no se ha observado ningún efecto significativo. A pesar de los daños notables en localidades específicas, los datos sugieren que las comunidades someras sobre sustrato rocoso en el Mediterráneo son bastante resistentes al efecto de tormentas extremas.

Abstract

We quantified multiple times before and after the storm the benthic and fish communities at 12 locations scattered over a distance of 50 km in the north of the Costa Brava as well as at other 126 locations along the rest of the Catalan coast. The storm caused no differences on the functional richness, evenness, or diversity but led to significant changes in community organization at the Costa Brava. Here, the benthic percent cover of bare rock and hydrozoans significantly increased after the storm, most likely at the expenses of foliose algae. Our data suggest that the storm simply wiped out a small percentage of erect algae in this area and generated additional free space that were used by a number of species, changing the organization of the community but causing no significant impact on the functional traits of the ecosystem. Along the rest of the Catalan coast, lacking a detailed analsyis of the database, no significant effects have been detected. Despite major damage in specific locations, our data also suggest that Mediterranean shallow rocky communities are resistant to the disturbance caused by severe storms.

Introduction

We all are aware of the devastating consequences that some natural disturbances cause to our economy and environment. The flooding and wind force associated with hurricane Katrina generated over $350 Billion of infrastructure damage alone (Burton and Hicks, 2005). Katrina destroyed residential, commercial, and industrial buildings, disabled critical infrastructure components such as

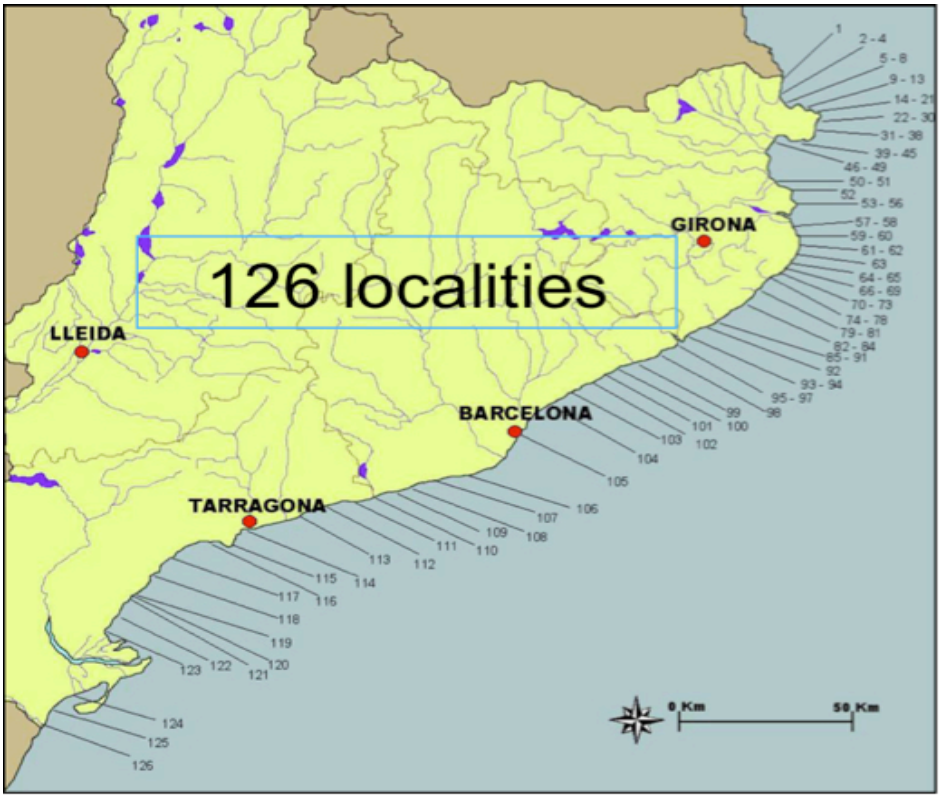

Figure 1. The 126 locations along the Catalan coast monitored for the detection of the invasive species *Caulerpa taxifolia* funded by the Agència Catalana de l'Aigua, Generalitat de Catalunya.

electrical transmission, water, and sewage services, raised a long list of concerns on human health hazards and long-term environmental impacts, and caused a number of challenges to reconstruct and restore urban and natural environments (Burton and Hicks, 2005; Pardue et al., 2005; Kates et al., 2006; Presley et al., 2006; Day et al., 2007; Schwab et al., 2007). Hurricanes can also have devastating ecological consequences that are usually put on the backburner and often overlooked. The ecological consequences of Katrina include but are not restricted to the effects the hurricane on carbon footprint (Chambers et al., 2007), wetland sedimentation (Turner et al., 2006), seagrass structure and function (Anton et al., 2009), or mortality of benthic invertebrates (Poirrier et al., 2008).

Disturbance is a critical process in community organization and diversity (Dayton, 1971; Sousa 1979). Maximal levels of species diversity can only occur at intermediate levels of disturbance (Connell, 1978) and severe storms could therefore play a major role in shaping communities, including marine benthic communities. However, these submerged communities lack the continuous observation that terrestrial environments have and the role of storms in shaping benthic communities remains unclear. For example, the impact of hurricanes on Caribbean seagrass beds show small patches of several square meters devoid of vegetation but destruction of entire sections is infrequent (Cruz-Palacios and van Tussenbroek, 2005; Byron and Heck, 2006; Steward et al., 2006). Contrarily, cyclones in Australia can destroy thousands of square kilometers of segrass beds (Preen et al., 1995). Many studies suggest that the effects of cyclones, typhoons, or hurricanes are restricted to shallow water areas, yet coral destruction can be lower in shallow areas as compared to deeper areas (Harmelin-Vivien and Laboute, 1986; Bries et al., 2004). Also, swell associated with not-so-severe storms can have pronounced effect on the benthic communities below 20m (Becerro et al., 2006). Beyond the literature on tropical storms, the information available on the consequences that storms have in marine benthic communities is limited (Posey et al., 1986). Clearly, more research is needed to improve our understanding of the impact that storms have on the organization and diversity of marine benthic communities.

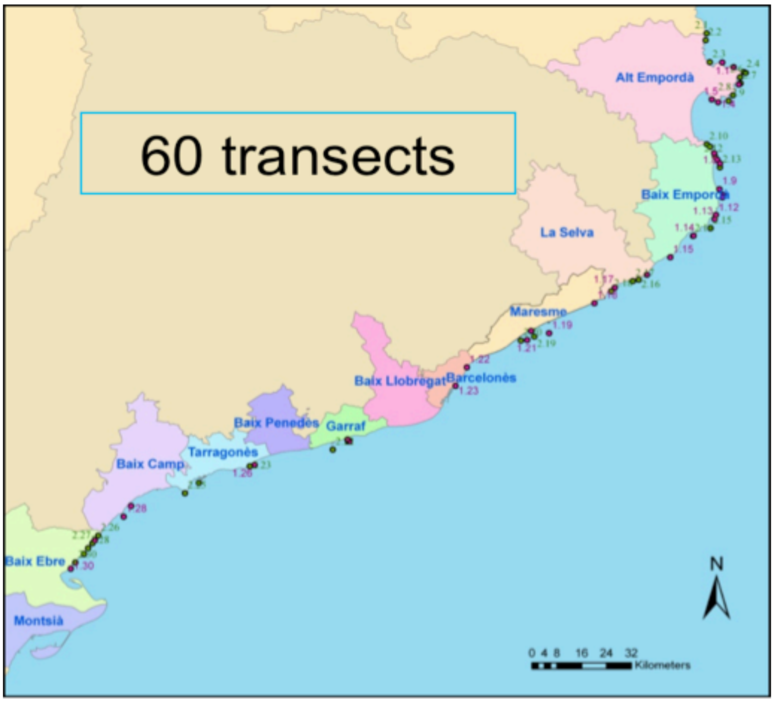

Figure 2. Location of the 60 transects monitored in 2006 and 2009 along the Catalan coast, from the surface to about 40 m depth, for the detection of the implantation of exotic species.

Seldom have we had a chance to investigate the effects of a major storm in shallow rocky communities. We were monitoring species diversity and community organization of shallow rocky communities in the Costa Brava when a severe storm stroke the Catalan coast on December 26, 2008 (Sant Esteve). The storm lasted for three days and generated waves over 14m of height, being the largest wave height ever recorded by

Table 1. Depth (in m), orientation, and dates of sampling for each of the 12 locations investigated in this study.

Location	Depth	Orientation	Dates of sampling	
			Before	*After*
Els Caials	12	S	May 07; Feb, May, Oct 08	Feb 09
Montjoi	4	E-NE	May 07; May, Oct 08	Feb 09
Cala Culip	7	S-SE	May 07; May, Oct 08	Feb 09
Mateua	4	NO	May 07; May, Oct 08	Feb 09
Port Bou	8	E	May 07; Feb, May, Oct 08	Feb 09
Faro Sarnella	8	N	May 07; May, Oct 08	Feb 09
Tascons	12	E	May 07	Feb, May 09
Pedra de Deu	7	N	May 07	Feb, May 09
Cueva de la Vaca	6	S	May 07	Feb, May 09
Punta Salinas	8	SE	May 07	Feb, May 09
Cala Falguer	9	S	May 07	Feb, May 09
Illa Pedrosa	8	SE	May 07	Feb, May 09

the buoys of Roses and Palamós (see Chapter 1). This unprecedented storm swell caused a number of fatalities and extensive damage in harbors, waterfront esplanades, strands, and other coastal infrastructures that caused a loss of millions of Euros and captured national attention in the media (RTVE, 2008; La Vanguardia, 2008; 3cat24, 2009, El Periodico, 2009; La Costa Digital, 2009). A number of marine biologists were concerned about the consequences that the extreme swell could have caused to marine benthic communities and joined forces in a collaborative attempt to investigate the ecological effects of this storm and to shed light on the role that storm associated disturbances cause to a variety of marine benthic communities.

The goal of this study was to assess the general impact of the Sant Esteve's storm by testing for differences in the functional traits of the community. Functional traits are critical to assure ecosystem functionality and many ecosystem processes and services depend more on functional diversity than species diversity per se (Nyström 2006). Specifically, we quantified number and abundance of functional groups, richness, evenness, and diversity (Shannon index) in multiple times and locations of the north of the Costa Brava before and after the storm. Our data included observations along multiple seasons and years, incorporating a large degree of variation that provides an unique perspective to investigate the effect of the storm at a large scale, beyond the specificities of a single location or season. Our data show significant changes in the abundance of some groups of species, but the overall effect of the storm failed to cause shifts in the functional traits of shallow rocky communities, suggesting they are resistant to natural disturbances of this magnitude.

Materials and Methods

Study site and community description

Costa Brava

From May 2007 to May 2009, we sampled multiple times 12 locations in the north coast of Girona to quantify the abundance of fish, algae, sessile invertebrates, and echinoderms (Table 1). We combined species into functional groups because they represent ecologically distinct and relevant groups suitable to examine overall changes in benthic community (Villamor and Becerro, 2010). These procedure allowed a detailed description of the number and abundance of functional groups as well as the functional richness, evenness, and diversity because they impartially quantify the sessile community and major consumers in the system (Villamor and Becerro, 2010).

In each location, we haphazardly placed a 50-m transect line between 5 and 10 m depth. We used underwater visual census (UVC) in a 2-m-wide strip at each side of the transect line to quantify fish abundance. Specifically, we recorded the number of fish specimens belonging to the most common and abundant demersal fish families in the study area (Labridae, Sparidae, and Serranidae). *Sarpa salpa* (Linnaeus 1758) was treated independently of the family Sparidae to which it belongs because it is a strict herbivore with a strong aggregating behavior as opposed to the remaining sparid species which are carnivores or omnivores.

In the same transect line we quantified the sessile composition by recording every 50 cm the organism present underneath the line (point-intercept method, 100 points total). Crustose coralline algae (also referred to as encrusting red algae, corallines or crusts, following Steneck et al. 1991) such as *Lithophyllum sp*., *Mesophyllum sp*., and *Peyssonnelia sp*. were recorded when not overgrown by other algal species (Tuya and Haroun 2006). Species of sessile invertebrates were also classified according to their zoological group as sponges, bryozoans, ascidians, hydrozoans, anthozoans, and cirripeds. We also quantified the number of sea urchins and number of the sea stars *Echinaster sepositus* and *Marthasterias glacialis* (Linnaeus 1758) along a 50-m^2- wide strip, centered in the transect line. The most abundant sea urchin species in the area was *Paracentrotus lividus* (Lamarck 1816). A few specimens of the sea urchin *Arbacia lixulalixula* (Linnaeus 1758) were noticed in some transects, although numbers were low as this species inhabits preferentially artificial breakwaters (Palacin et al. 1998b). To facilitate underwater quantification, we included both

Table 2. Rotated loading matrix obtained by the factor analysis (FA) on the percent cover of the 19 functional groups (including bare rock) quantified in the 12 locations before and after the storm.

Functional group	Factor						
	FA1	FA2	FA3	FA4	FA5	FA6	FA7
Foliose algae	-0.841						
Crustose algae	0.769						
Sponges	0.642						
Bare rock	0.567						
Hydrozoans		0.818					
Ascidians		0.806					
Labrids			-0.842				
Leathery algae			-0.784				
Calcareous algae			-0.600				
Serranids				0.855			
Sea urchins				0.755			
Sparids				0.548			
Corticated algae				0.532			
Sea stars					0.787		
Salpa					0.602		
Barnacles						0.685	
Antozoans						-0.659	
Sciaenids							-0.725
Filamentous algae							-0.513
% variance explained	*13.25*	*10.63*	*11.69*	*11.01*	*8.38*	*8.98*	*7.32*

To facilitate interpretation, we only showed coefficients with absolute value larger than 0.5. The resulting independent factors after FA explained 71.26% of the total variance.

species in our sea urchin category as main invertebrate grazers on these communities.

Analytical rationale

We used statistical methods available in PRIMER 6 software (Clarke and Warwick, 2001) and Systat 12 (SPSS, 1999) to test for significant differences in our species data before and after the storm. First we calculated Bray–Curtis similarity on squareroot-transformed species abundance and used permutational multivariate analyses of variance (PERMANOVA) to test for the effect of the storm. We also run a similarity breakdown to obtain the contribution of each species to the overall dissimilarity of the communities before and after the storm. This multivariate approach used all the data we gathered and it is optimal to draw conclusions on the overall effect of the storm.

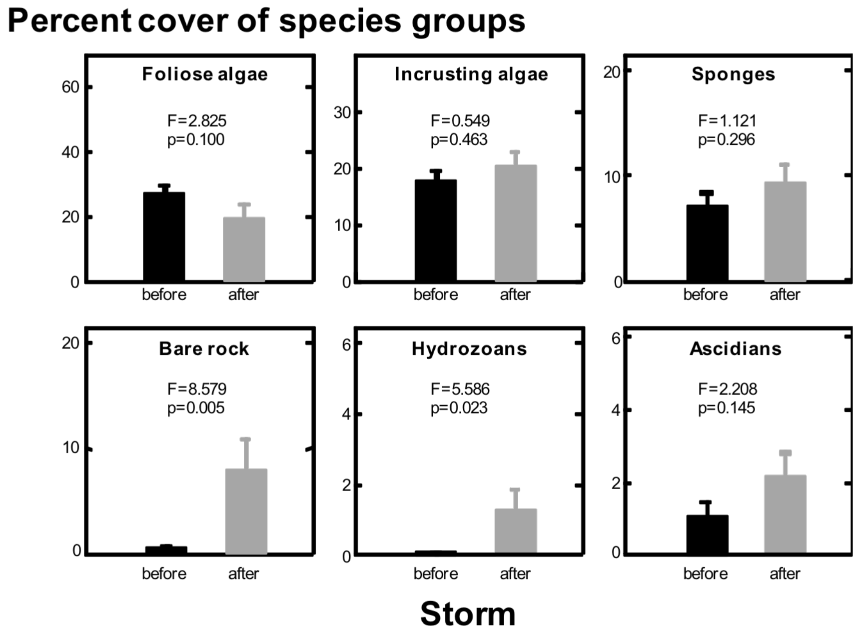

Figure 3.- Mean percent cover (±SE) of the species groups included in the factors that varied significantly before and after the storm. Univariate F statistics and p values shown. Only Bare rock (factor 1) and Hydrozoans (Factor 2) varied significantly before and after the storm. Note differences in scales.

Because of the large number of species quantified in this study (over 100 species grouped in 19 functional categories), we used factor analysis (FA) to look for coherent groups of functional categories that were correlated with one another within groups but largely independent between groups (Tabachnick and Fidell, 2001). These groups of correlated functional groups (so called factors) help interpret the underlying mechanisms that have created the relationship between them. Specifically, we used a principal component analysis extraction (PCA) with a minimum eigenvalue of one to estimate number of factors. To facilitate interpretation, we used varimax rotation since it minimizes the number of functional groups that load highly on a factor and maximizes the loading variance across factors. The resulting independent factors were used as variables in multivariate analysis of variance (MANOVA) to test for the effect of the storm on these groups of functional categories. Factors that differed significantly before and after the storm were further analyzed by testing for differences in the abundance of the functional groups included in the factor to reveal the actual functional groups that shifted with the storm disturbance.

Rest of the Catalan Coast

To allow for an early detection of the implantation of the invasive seaweed *Caulerpa taxifolia*, we are monitoring 126 locations along the Catalan coast since 1992 (Figure 1 and annex 1). Sampling sites include anchoring bays, beaches and harbours. The surveys were done at a maximum depth of 10 meters using mask,

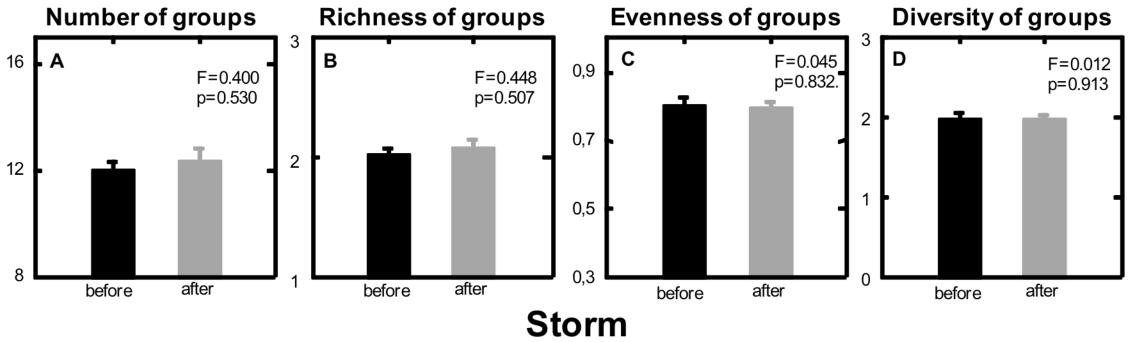

Figure 4. Mean (±SE) of the number (A), richness (B), evenness (C), and diversity (D) of the functional groups. Note differences in scales.

snorkel and fins from the shore or from a rubber boat.

Additionally, since 2006, 60 transects also along the Catalan coast are being periodically surveyed for detecting the introduction of exotic species. The transects are located in specially susceptible locations such as exposed capes or open sea reefs (Figure 2). Surveys are performed using SCUBA following a bathymetric transect from the surface to the maximum depth of about 40 m (where the rocky substrate ends and the sandy bottom begins to dominate). All present species are recorded (Annex 1 and 2) with a semiquantitative value related to their abundance (adapted from Braun Blanquet 1979). Examples of targeted species are *Asparagopsis taxiformis*, *Lophocladia lallemandii, Womers-leyella setacea, Acrothamnion preissi,* or *Caulerpa racemosa* v. *cylindracea.*

Results and Discussion

Costa Brava

Overall, the shallow rocky communities investigated in this studies differed significantly before and after the storm (PERMANOVA, F= 2.766, p=0.006). Seven functional groups accounted for almost 60% of the differences: sea urchins (av. diss=4.34, 13.51%), *Sarpa salpa* (av. diss=3.01, 9.38%), corticated algae (av. diss=2.56, 7.96%), foliose algae (av. diss=2.38, 7.39%), Sparids (av. diss=2.28, 7.09%), labrids (av. diss=1.95, 6.07%), and bare rock (av. diss=1.93, 6.00%).

Our factor analysis reduced 19 functional categories to 7 factors that explained over 70% of the total variance in our data (Table 2). Multivariate analysis of variance on those factors supported the PERMANOVA results (F=3.544, p=0.005). Out of the seven factors, only Factor 1 and Factor 2 varied before and after the storm (univariate F tests, F=5.057, p=0.030 and F=5.441, p=0.025 respectively). Factor 1 grouped together foliose and incrusting algae, sponges, and bare rock while Factor 2 grouped hydozoans and ascidians (Table 2). The percent cover of bare rock and hydrozoans increased significantly after the storm while the remaining groups showed no significant differences (Figure 3).

The number of functional groups failed to vary before and after the storm (Figure 4A). The identity of observed functional groups before and after the storm were identical except for the low abundant Sciaenidae fish family, which we only observed before the storm. The richness, evenness, and diversity of functional groups also failed to vary before and after the storm (Figure 4B, C, and D, respectively).

Our study showed changes in the shallow rocky communities of the Costa Brava before and after the severe storm of December 26, 2008. These changes were driven by a significant increase in percent cover of bare rock. Given that free space on where to settle and grow is scarce for these communities (Turon et al., 1996; Becerro et al., 1997), the possibility of strong implications in spatial interactions looms large (Uriz et al., 2011). We also observed an increase in hydrozoans, which could have occupied part of the free space available benefited from a new set of conditions after the storm. The additional space generated in these communities seem to stem from a reduction in the percent cover of foliose algae and other sessile species.

It is worth noting that most of the species groups that contributed to the dissimilarity in the community before and after the storm showed no significant differences in abundance or percent cover (e.g., sea urchins, corticated and foliose algae) in our analyses. Because our data included data from multiple locations and times, the differences associated with the storm event must be larger than the spatial and temporal variability in these seasonally fluctuating communities (Ballesteros, 1991; Becerro et al., 1997; Marti et al., 2005). A direct comparison of a community right before and after a storm would likely show larger differences. Despite the need and importance of such studies, they are locally important and could overestimate the role of storm events in the organization of the community because they fail to account for the spatial and temporal variability that occurs in such community (Posey, 1986). Thus, our results may look minor because significant changes were limited to a few species groups, but the changes are truly relevant because they surpassed a remarkable variability in the system. Also, the contribution of numerous non-significant effects could be behind the significant effect at the community level found in our study, as suggested by our similarity breakdown analysis and univariate F tests.

Despite the changes in community organization before and after the storm, our data suggest that these communities are truly resistant against such an infrequent disturbance event. The storm generated swell that had never been recorded before, which highlights the extreme nature of the storm. Despite the magnitude of the disturbance, the functional traits of shallow rocky communities were virtually identical. Since functional diversity is directly linked to ecosystem services and function (Nyström, 2006), it is unlikely that these types of events by themselves can lead to a shift in the community. However, the likely increasing occurrence of extreme storms associated with the increasing extraction of natural resources, habitat pollution and degradation could result in a phase shift as reported for coral reefs (Gardner et al., 2003).

Rest of the Catalan coast

The data corresponding to the surveys performed along the rest of the Catalan coast could not be performed in time to be included in this report, as the type of field data entry is requiring a special treatment to make them suitable for a proper statistical analysis. A joint paper compiling all data sources is planned in a near future. Nevertheless, a rough comparison of the datasets available before and after the storm does not reveal any conspicuous difference in abundance or in species composition.

Concluding comments

The data available for the Costa Brava showed evidence for significant changes in the abundance of a few functional groups as a consequence of the severe storm on December 26, 2008. These changes were driven by the increased percent cover of bare rock. We set forth the hypothesis that the additional free space allowed hydrozoans and perhaps other species to increase their relative abundance. Whether these differences might be sustained in time is unknown, but it seems reasonable to assume that they will fail to jeopardize the stability of shallow rocky communities as the storm caused no impact on the functional richness, evenness, and diversity of the community.

To the south Costa Brava, the transects monitored did not reveal any significant effect as a consequence of the storm in the communities on rocky substrate from the surface to about 40m depth.

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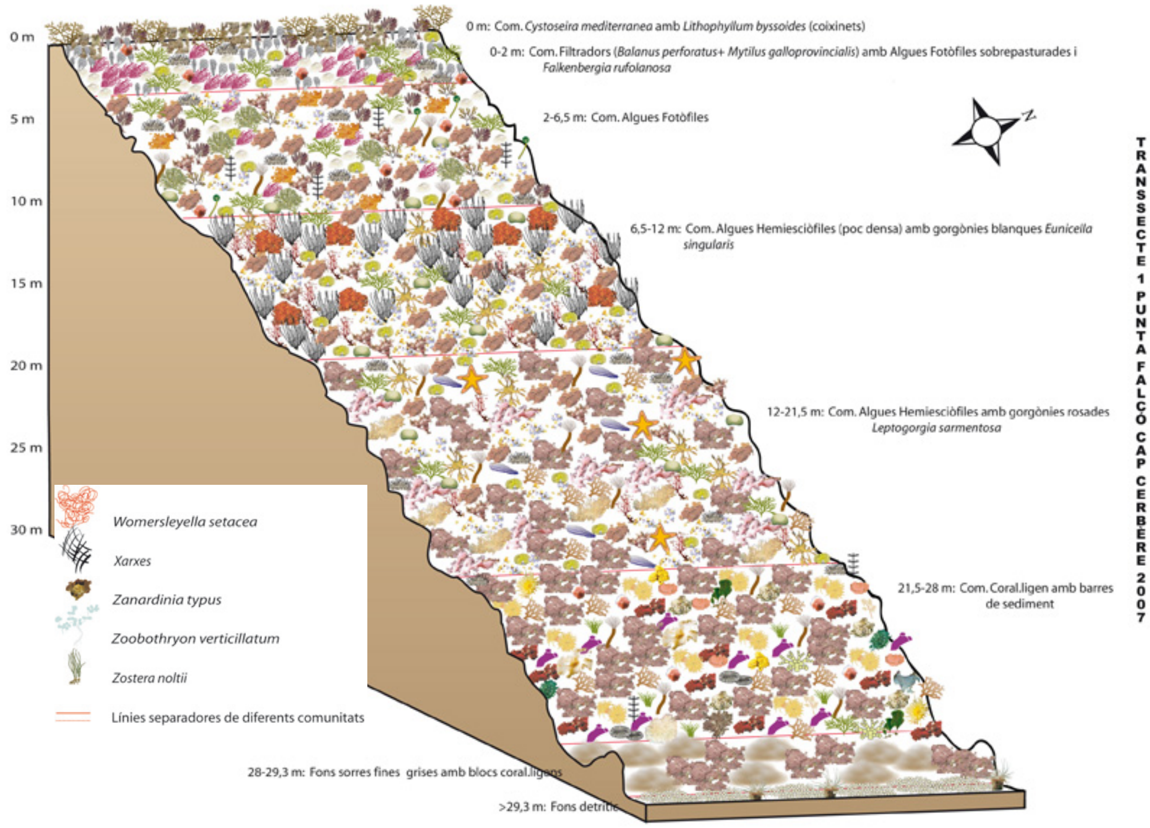
Annexes

Annex 1. An image of the SCUBA operations for the monitoring of the communities of rocky substrate along the Catalan coast. All the organisms within 40x40 quadrants were recorded from 0 to about 40 m of depth.



Annex 2. An example of the graphic output of the results of the monitoring along the Catalan coast for the detection of exotic species (Agècia Catalana de l'Aigua of the Generalitat de Catalunya, project CTN0802811).