Fan mussel (*Pinna nobilis*)

Antoni Garcia-Rubies[1], Pedro Lázaro[2], Àlex Lorente[3], Miguel Ángel Mateo[1]

[1]Centro de Estudios Avanzados de Blanes. Consejo Superior de Investigaciones Científicas.
[2]Independent naturalist.
[3]Parc Natural del Montgrí, les Illes Medes i el Baix Ter.

Abstract
The effect of the easterly storm of S. Esteve (2008) on *Pinna nobilis* populations was assessed in to areas of the Costa Brava. In Giverola Cove, 33% of the individuals died as a consequence of the storm. In Medes Islands, the population directly exposed to the east waves disappeared, while that sheltered by the Meda Gran was unaffected. The orientation to the storm and the nature of the bottom have been identified as critical factors determining *P. nobilis* survival to the effects of an extreme storm.

Image: *Pinna nobilis*, Tossa de Mar, by Víctor Cebollada

Garcia-Rubies, A., Lázaro, P., Lorente, A., Mateo, M.A. (2012). Effects of 2008 Sant Esteve's storm on *Pinna nobilis* populations in the Costa Brava (NW Mediterranean): the study cases of Giverola Cove and the Natural Reserve of the Medes Islands. 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. 157 – 170.

Proyecto Intramural Especial Cofinanciado CEAB-CSIC, PIEC 200430E599
FINAL REPORT, p. 157 – 170, April 2012

Effects of 2008 Sant Esteve's storm on *Pinna nobilis* populations in the Costa Brava (NW Mediterranean): the study cases of Giverola Cove and the Natural Reserve of the Medes Islands

By

Antoni Garcia-Rubies[1*], Pedro Lázaro[2], Àlex Lorente[3], Miguel Ángel Mateo[1]

[1]Centro de Estudios Avanzados de Blanes. Consejo Superior de Investigaciones Científicas. Acceso a la Cala S. Francesc 14. 17300 Blanes, Spain.
[2]Naturalista independiente (plazaromateo@hotmail.com). Victor Català, 20 Bl.H, 4º 1ª, 17320 Tossa de Mar, Girona, Spain.
[3]Parc Natural del Montgrí, les Illes Medes i el Baix Ter. Passeig del Port, s/n. Espigó de Llevant. 17258 L'Estartit, Girona, Spain.
*tonigr@ceab.csic.es

Resumen

El efecto del temporal de levante de S. Esteve (2008) sobre de *Pinna nobilis* fue estudiado en dos zonas de la Costa Brava. En Cala Giverola , el 33% de los individuos murieron debido al temporal. En las Illes Medes, la población directamente expuesta al oleaje del Este, fue totalmente devastada, mientras que la situada a resguardo de la Meda Gran resultó intacta. La orientación al temporal y la naturaleza del fondo se han identificado como factores críticos para la supervivencia de *P. nobilis a* los efectos de un temporal extremo.

Abstract

The effect of the easterly storm of S. Esteve (2008) on *Pinna nobilis* populations was assessed in to areas of the Costa Brava. In Giverola Cove, 33% of the individuals died as a consequence of the storm. In Medes Islands, the population directly exposed to the east waves disappeared, while that sheltered by the Meda Gran was unaffected. The orientation to the storm and the nature of the bottom have been identified as critical factors determining *P. nobilis* survival to the effects of an extreme storm.

Introduction

The fan mussel *Pinna nobilis* is the largest endemic Mediterranean bivalve. It can exceed one metre in length and 37 years of age (http://www.pinnanobilis.free.fr; Zavodnic *et al.*, 1991). Fan mussels live partly buried in sandy bottoms, and are strongly anchored by the byssus. Although it is normal to find them associated with *Posidonia oceanica* or *Cymodocea nodosa*, they can also be found in bare sandy or muddy bottoms (Katsanevakis, 2005; Addis *et al.*, 2009). They are found in highly variable densities, ranging from 0.03 ind 100m^{-2} to above 30 ind 100m^{-2} (Addis *et al.*, 2009). The buried part of the animal reaches about one third of the total length of the animal (Zavodnik et al., 1991) and the part that emerges is obviously vulnerable to predation, which is more accentuated in juveniles (Vicente, 1990; Vicente and Moreteau, 1991; Fiorito and Gherardi, 1999). Larger specimens can be threatened by the action of severe hydrodynamic conditions and high shear stresses (Foulquie and de la Dupuy, 2003; García-March, 2003), the effects of which are exacerbated by the large size and rigidity of the bivalve . Wave action on fan mussel populations is considered to be one of the determining factors in the bathymetric distribution of the species, and the larger specimens are usually found deeper than the small ones. According to Zavodnik (1967) and Vicente *et al.* (1980) this implies that survival is lower in shallow waters, since the shear stress at the bottom is a function of the square of water velocity and increases with decreasing depth. As the fan mussel is a filter feeder, it is evident that the viability of the animal is in a delicate balance: a certain degree of hydrodynamism is necessary for the fan shell to feed, but hydrodynamic conditions that are too heavy can dislodge and kill the animal. It is also evident that the exposed surface increases with the size of the shell, which implies an increase in the dragging force which the fan mussel must oppose with the byssus (García-March *et al.*, 2007). In defence against these forces, fan mussels tend to position their shells towards the main dominant currents (García-March *et al.*, 2007); however, this adaptation can be fatal when extreme infrequent storm events occur.

Due to its slow growth rate and to its historical decline in the Mediterranean (Richardson *et al.*, 1999), both at the national and international levels, various directives protect and ban the exploitation of the fan mussel. It is included in Annex IV of the directive 92/43/CEE of the Habitats Directive, which lists the species of plants and animals of interest in the European Union that require strict protection. Similarly, it has been declared a threatened or endangered species in the Mediterranean by the Protocol of Barcelona 1996 and ratified in Bern 1999. As anchoring boats is prohibited in the Medes Islands Natural Reserve, the fan mussel population around these islands is one of the densest in the Mediterranean.

The effect of a storm on a fan mussel population has already been documented by García-March *et al.* (2007); however, the immediate mortality associated with an exceptional storm of the magnitude of that which occurred on the Catalan coast in December 2008 has never been investigated. This storm was especially violent on the Costa Brava, with a significant wave height (H_S) above 7m and individual wave heights exceeding 12 m high, with a maximum of 14.4m recorded in Palamós. In this study we present two case studies of the effect of the storm on fan mussels in two locations of the Costa Brava (northern Spanish Mediterranean coast). In both cases, detailed descriptions and the precise location of fan mussel individuals were

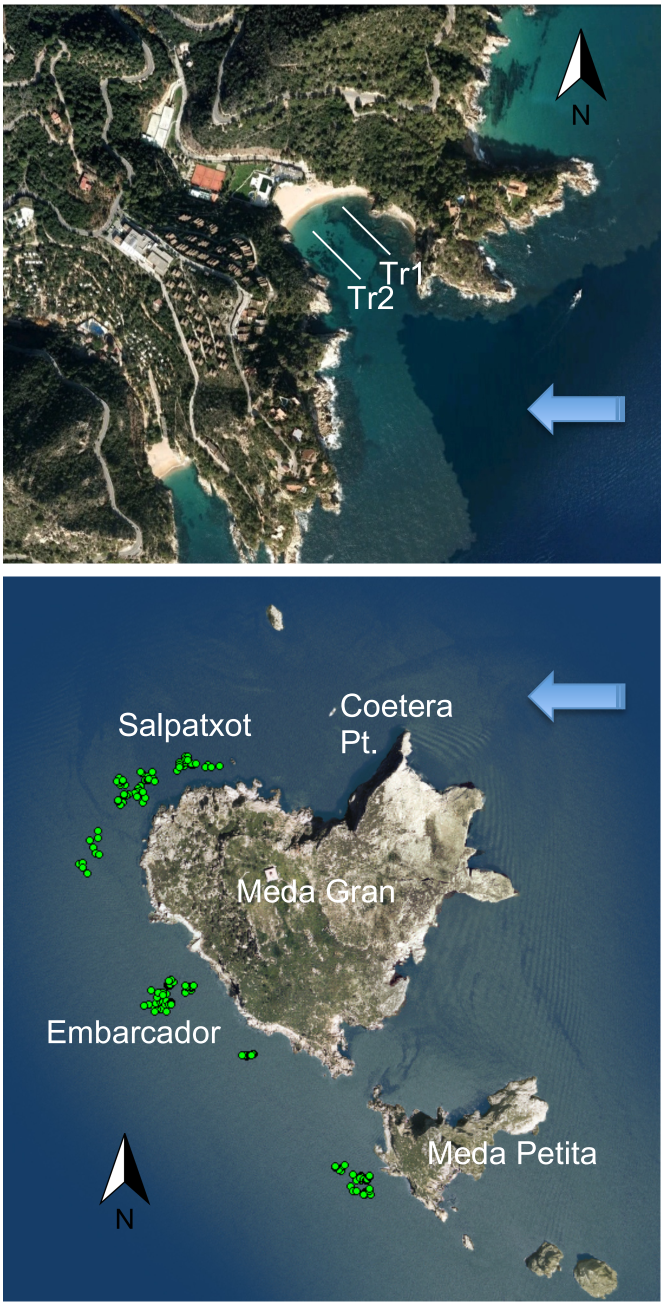


Figure 1. Top: Transects surveyed in Cala Giverola. Bottom: Surveyed sites and individuals of *Pinna nobilis* in Medes Islands (green dots) in their geo-referenced position in the *Posidonia oceanica* meadows around the Medes Islands. The blue arrow indicates the mean wave direction during the storm of Sant Esteve (90º).

available before the storm, and were then surveyed after the event.

Materials and Methods

Site and field observations

Observations were made at Giverola Cove (GC) and at the Medes Islands Natural Reserve (MI) (Fig. 1). The population at GC has been monitored since 30 October 2007 (by the naturalist Pedro Lázaro). The last survey before the storm was carried out on 18 December 2008. Two transects of ca. 100 m at 5 to 7 m depth were established on both sides of GC covering the areas indicated in Figure 1 (top). The total area surveyed was ca. 300 m^2. In each transect the specimens were individually numbered, geo-referenced and measured, taking into account the length or emerged height (Hs), the dorso-ventral emerged length or maximum width (Wc), and the width at the sediment level (Ws). The orientation of the shell was also recorded by means of an underwater compass. During the monitoring period, the history of each specimen was recorded, noting the different causes of death if possible: predation, hydrodynamics (dislodged shells torn by waves), partial and total burial (disappearance of the valves), human action (taken away, anchorage, etc.), natural death (aging, disease) or unknown causes.

The monitoring came to an abrupt end when the storm hit the study area from 26 to 28 December, 2008. The first survey after the storm was made on 2 January 2009 and proved to be an invaluable source of data for documenting the immediate mortality caused by the storm.

In the Medes Islands during August 2007, a total of 167 fan mussels were studied in the three main zones of the islands where there are *Posidonia oceanica* meadows (Salpatxot, Embarcador and Meda Petita, Fig. 1, bottom). The total area covered by the survey was about 3 ha and was located between 5 and 15m depth. The bottom in Salpatxot is a combination of sand and loose small-sized stones (5 to 20 cm in diameter). In Embarcador, the bottom is mainly formed by coarse sand sediments. Every individual was geo-referenced and located by inserting a labelled stick in the sand next to it. Photographs and the biometric features of both valves were recorded for each individual. During February 2009, 2 of the 3 areas studied in 2008 were revisited: one exposed (Salpatxot) and one sheltered (Embarcador) from the storm.

Data treatment

We calculated the correlation coefficients (*Pearson r*) between Hc, Wc and Ws. The dimensions of the individuals were compared according to their position in transect 1 or 2 and also among the specimens that were killed by the storm, those that died due to other causes and those that were still alive at the end of the monitoring period. Size distributions were compared by means of non-parametric Kolmogorov-Smirnov tests, using the statistical package *Statistica* 6.0 ©.

Results

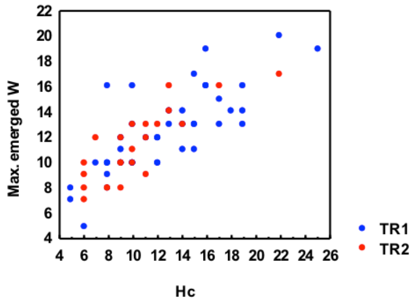
Giverola Cove

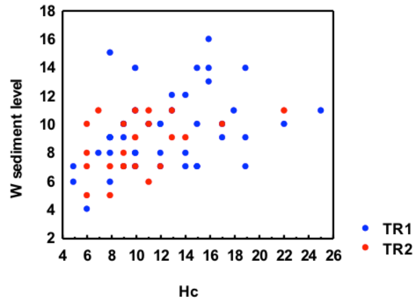
Of the total 78 individuals found in the cove (53 in transect 1 and 25 in transect 2), 67 were measured during the different SCUBA surveys (44 in transect 1 and 23 in transect 2). Good correlations were obtained between the height and width of the emerged shell (Hc *vs* Wc; r = 0.80, p <0.001) and between the maximum width and the width at the sediment level (Wc *vs* Ws; r = 0.80, p <0.001). Somewhat lower, but still significant, was the correlation between the maximum height and the width at the sediment level (Hc *vs* Ws; r = 0.41, p <0.001; Fig. 2). In general, specimens were small to medium sized, although the specimens in transect 1 were slightly larger than those in transect 2 without significant differences (Table 1). The average orientation of the valves of the fan mussels was of 182º (sd: 109) in transect 1 and 180º (sd: 114) in transect 2. No significant differences in the orientations were observed between the two transects.

Of the initial number of individuals recorded, 40% were found alive at the end of the monitoring period after the storm. Of the 60% that died, 27% died due to different causes and 33% were killed directly by the storm. The mortality was different in the two transects: in transect 2 (slightly more exposed than transect 1), 68% of the initial population was killed as a consequence of the storm, whereas mortality prior to the storm only

Table 1. Summary of the Kolmogorov-Smirnov tests among size measurements of the specimens killed by the storm (Storm) against the specimens dead before the storm (Other) and the survivors at the end of the monitoring period (Alive).

	Max Neg Diff.	Max Pos Diff.	p	Mean Storm	Mean Alive	SD. Storm	SD Alive	N Storm	N Alive
Hc	-0,467	0,00	p < .01	9,750	13,800	3,603	4,574	24	30
Wc	-0,567	0,00	p < .001	10,458	13,833	2,395	2,902	24	30
Ws	-0,450	0,00	p < .01	8,000	10,633	1,794	2,385	24	30
	Max Neg Diff.	**Max Pos Diff.**	**p**	**Mean Other**	**Mean Alive**	**SD. Other**	**SD. Alive**	**N Other**	**N Alive**
Hc	-0,479	0,033	p < .05	10,538	13,800	3,455	4,574	13	30
Wc	-0,503	0,000	p < .025	10,615	13,833	2,755	2,902	13	30
Ws	-0,526	0,000	p < .025	8,231	10,633	2,315	2,385	13	30
	Max Neg Diff.	**Max Pos Diff.**	**p**	**Mean T**	**Mean Other**	**SD. T**	**SD. Other**	**Valid N T**	**N Other**
Hc	-0,199	0,042	p > .10	9,75	10,54	3,60	3,45	24	13
Wc	-0,103	0,077	p > .10	10,46	10,62	2,40	2,75	24	13
Ws	-0,131	0,109	p > .10	8,00	8,23	1,79	2,31	24	13





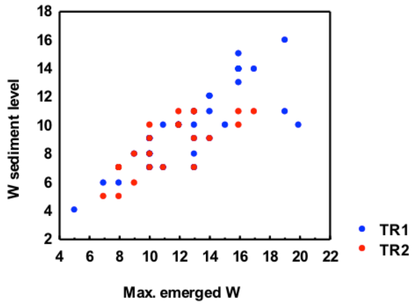


Figure 2. Correlations between the emerged height (Hc) and the largest emerged width (Wc); emerged height (Hc) and width at the sediment level (Ws), and maximum emerged width (Wc) *vs* width at the sediment level (Ws), in transect 1 (blue dots) and transect 2 (red dots).

affected 17% of the population; in transect 1 (relatively more sheltered), just 16% of the initial population was killed by the storm while 18% died due to other causes before the storm (Figures 4 and 5). The causes of mortality other than the storm were mostly for unknown reasons (presumably predation and anthropogenic causes) and there were no significant differences between the transects. Only two individuals were found to have been pulled up before the storm.

All individuals killed by the storm in transect 2 were victims of the sediment deposited by the storm (see also Chapter 11) and either disappeared due to being completely buried (53%) or died suffocated by partial burial (47%). Five specimens (56%) from transect 1 were killed due to dislodgement, 3 (33%) due to partial burial and 1 (11%) for unknown reasons.

A comparison of the sizes of the specimens that died as a consequence of the storm with those that died from other causes during the monitoring period and those that survived, showed that individuals who perished as a result of the storm were significantly smaller than the survivors, but did not differ statistically from those that died of other causes before the storm (Figure 6). The orientation of the shells did not differ significantly among the three groups.

The maximum tangential forces applied in CG were estimated to be 120 Nm^{-2} with an average of 87 Nm^{-2}. However, because the cove is open to the SE, it is likely that these forces were significantly lower.

Medes Islands

The *P. oceanica* meadows of the Salpatxot area showed striking evidence of the severe impact of the storm. The tangential forces applied in this area were up to 150 Nm^{-2} with an average of 90 Nm^{-2}. There may have been a very slight reduction in these forces due to the possible sheltering effect of Coetera Point. Some areas of the meadow were buried under sand and other areas were torn up (Annex 1). All 21 individuals counted before the storm had disappeared. No traces of fragmented or buried individuals were found. Evidence of movement of large stones and rocks was also observed. However, all the individuals labelled in the Embarcador area were found again in 2009 in perfect condition (Annex 2). The forces applied in this area were estimated to be up to 115 Nm-2 with an average of 78 Nm^{-2}, but cannot be taken into account because the model applied did not consider the presence of the Meda Gran, which totally shelters the area.

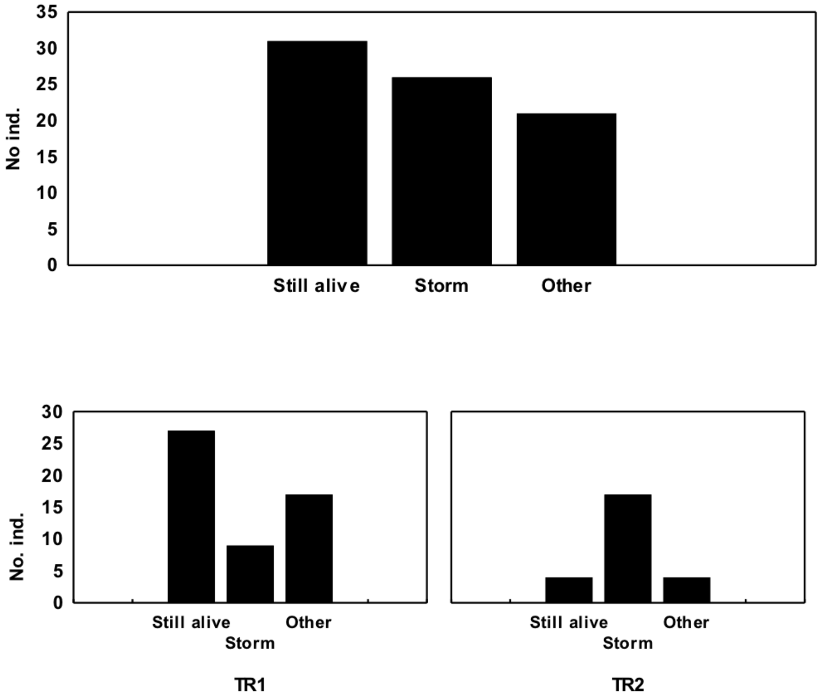


Figure 4. Number of survivors, individuals killed by the storm and dead before the storm (top: total data, bottom: in each transect).

Discussion

Giverola Cove

The results clearly evidence that the storm hit with different strengths in the two transects located in Giverola Cove; while transect 2 was directly affected by the waves, and received an important load of sediment, transect 1 showed some evidences of sediment removal. Only a few specimens were dislodged in transect 1, but many seem to have dissappeared under the sand in transect 2. Since many of the fan

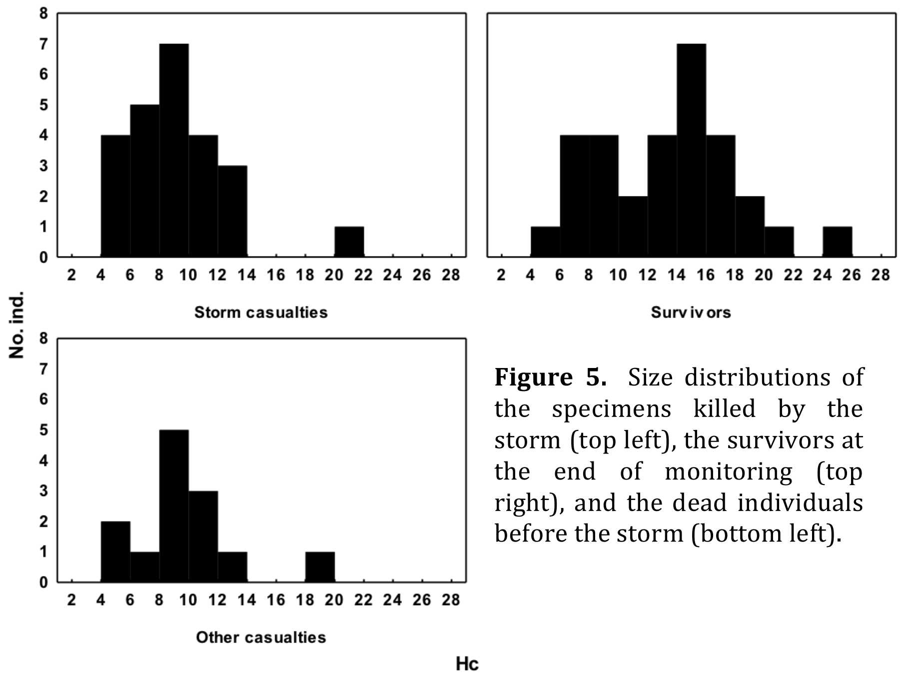


Figure 5. Size distributions of the specimens killed by the storm (top left), the survivors at the end of monitoring (top right), and the dead individuals before the storm (bottom left).

mussels were killed by partial or complete burial, it is logical that the orientation of the shells was not a significant factor in explaining such high mortality. In contrast, the size of the specimens did prove to be a determining factor, since specimens that died because of the storm were significantly smaller than those who survived. This is perfectly logical considering that most individuals were killed due to total or partial burial and, to escape being buried by sediment, a greater height is obviously an important advantage. But the size of the specimens that died from the storm did not differ from the size of those that died from other causes. This suggests that smaller individuals are more vulnerable than larger ones, which is also logical given that growing in height and width involves the shell becoming thicker. This confers greater resistance to predation, and also a stronger attachment to the substrate, which can make them more resistant to shear stress in spite of having a larger exposed surface. These observations are in accordance with those made by García-March *et al*. (2007) about the size-refuge effect. The results therefore suggest that fan mussels resisted a considerable shear stress caused by the storm in Cala Giverola reasonably well, but were very vulnerable to burial in the sheltered area of the cove.

Medes Islands

The impact of the storm on the population of *fan mussels* living in shallow waters (5-15m) of MI depended totally on the degree of exposure of the area to the wave direction. All of the individuals growing in the Salpatxot area (only moderately sheltered from the wave action by La Coetera Point) were lost. In this area, the type of substrate (small to medium sized rocks) also contributed to the severe impact of the storm. In this area, burial was not the mechanism behind the damage. No individuals surveyed in Embarcador (completely leeward of the Meda Gran) were lost and none were noticeably damaged.

Conclusions

A combination of four factors determined the impact of the Sant Esteve storm in 2008 on the populations of fan mussels on the Costa Brava: 1. the tangential forces applied (in turn depending on the orientation to the storm and the depth); 2. the type of substrate (sandy or rocks); and 3. the size of the individuals (the bigger, the more resistant). There was a large overall impact on the areas studied, with an overall loss of ca. 60% of the individuals labelled (as a direct consequence of the storm), representing about 50 individuals. Suffocation due to burial and abrasion by boulders were the two mechanisms that killed the fan mussels. This scenario, in which the organism seems to be more resistant to the shear stress than the substrate where it lives, has been found in other studies compiled in this report (see reports on e.g., *Posidonia*, gorgonians or algae, etc.).

We conclude that an easterly storm imposing tangential forces of 80 to 90 Nm^{-2} and over can cause dramatic effects on the endangered Mediterranean bivalve, *Pinna nobilis*.

Acknowledgements

The data from Medes Islands was obtained in the framework of the survey “Estudi pilot per a l'inventari i seguiment de nacres (*Pinna nobilis*) a diferents espais de l’àrea protegida de illes Medes”, carried out by Sánchez, J., Gazo, M., Lorente, A., in 2007 (umpublished). The authors wish to thank 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) and to Submon, subcontracted by the Parc Natural del Montgrí, les Illes Medes i el Baix Ter, for making the major part of the observations in Medes-Montgrí.

References cited

Addis, P., Secci, M., Brundu, G., Manunza, A., Corrias, S., Cau, A., 2009. Density, size structure, shell orientation and epibiontic colonization of the fan mussel Pinna nobilis L. 1758 (Mollusca: Bivalvia) in three contrasting habitats in an estuarine area of Sardinia (W Mediterranean). Scientia Marina 73, 143-152.

Fiorito, G., Gherardi, F., 1999. Prey-handling behaviour of Octopus vulgaris (Mollusca, Cephalopoda) on Bivalve preys. Behavioural Processes 46, 75-88.

Foulquie, M., de la Dupuy, G., 2003. Mise en place d'un suivi des grandes nacres (Pinna nobilis) dans la zone Natura 2000 des" Posidonies du Cap d'Agde", Hérault, France. Mémoires de l'Institut océanographique Paul Ricard, 49-55.

García-March, J., 2003. Contribution to the knowledge of the status of Pinna nobilis

(L.) 1758 in Spanish coasts. Mem Inst Oceanogr Paul Ricard 9, 29-41.

García-March, J.R., Pérez-Rojas, L., García-Carrascosa, A.M., 2007. Influence of hydrodynamic forces on population structure of Pinna nobilis L., 1758 (Mollusca: Bivalvia): The critical combination of drag force, water depth, shell size and orientation. Journal of Experimental Marine Biology and Ecology 342, 202-212.

Katsanevakis, S., 2005. Population ecology of the endangered fan mussel Pinna nobilis in a marine lake. Endangered Species Research 1, 51-59.

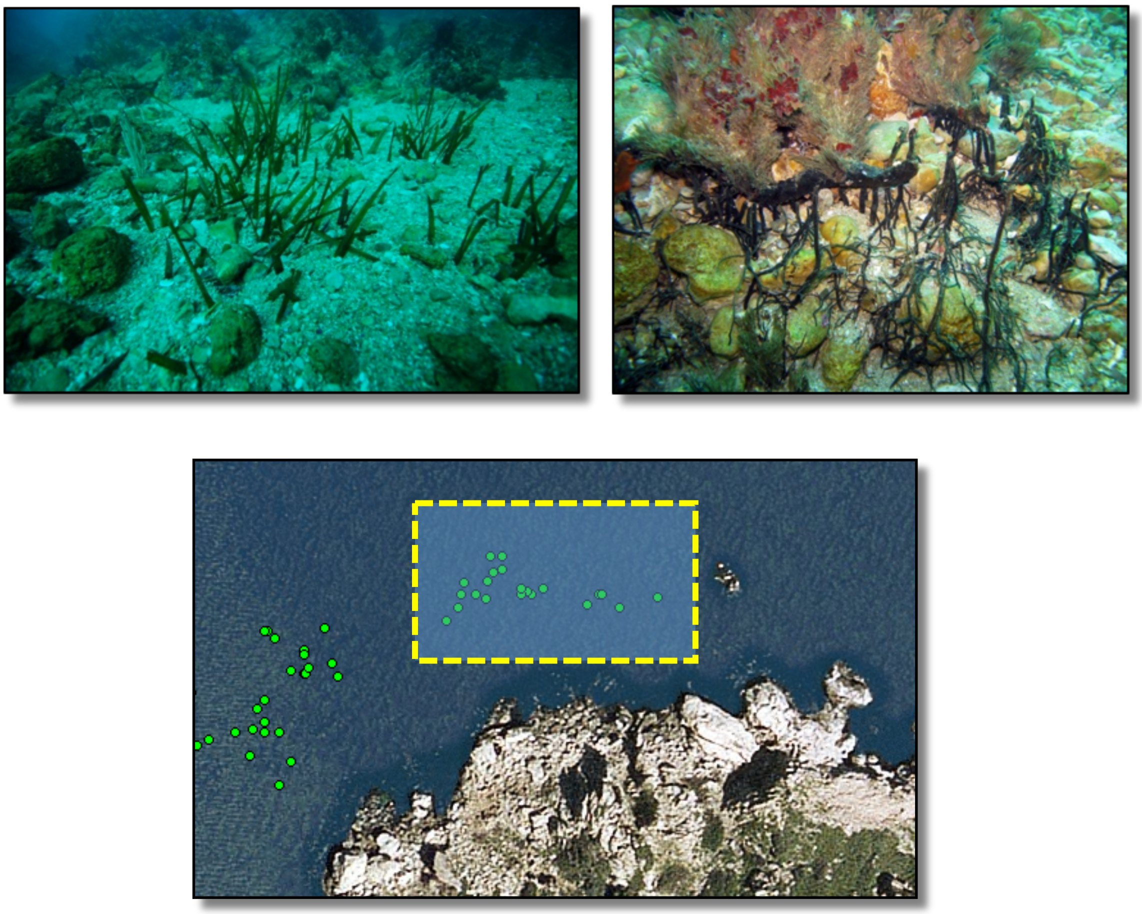
Richardson C.A., Kennedy, H., Duarte, C.M., Kennedy, D.P., Proud, S.V., 1999. Age and growth of the fan mussel *Pinna nobilis* from south-east Spanish Mediterranean seagrass (*Posidonia oceanica*) meadows. Marine Biology 133, 205-212.

Vicente, N., 1990. Estudio ecológico y protección del molusco lamelibranquio Pinna nobilis L. 1758 en la costa mediterránea. Iberus 9, 269-279.

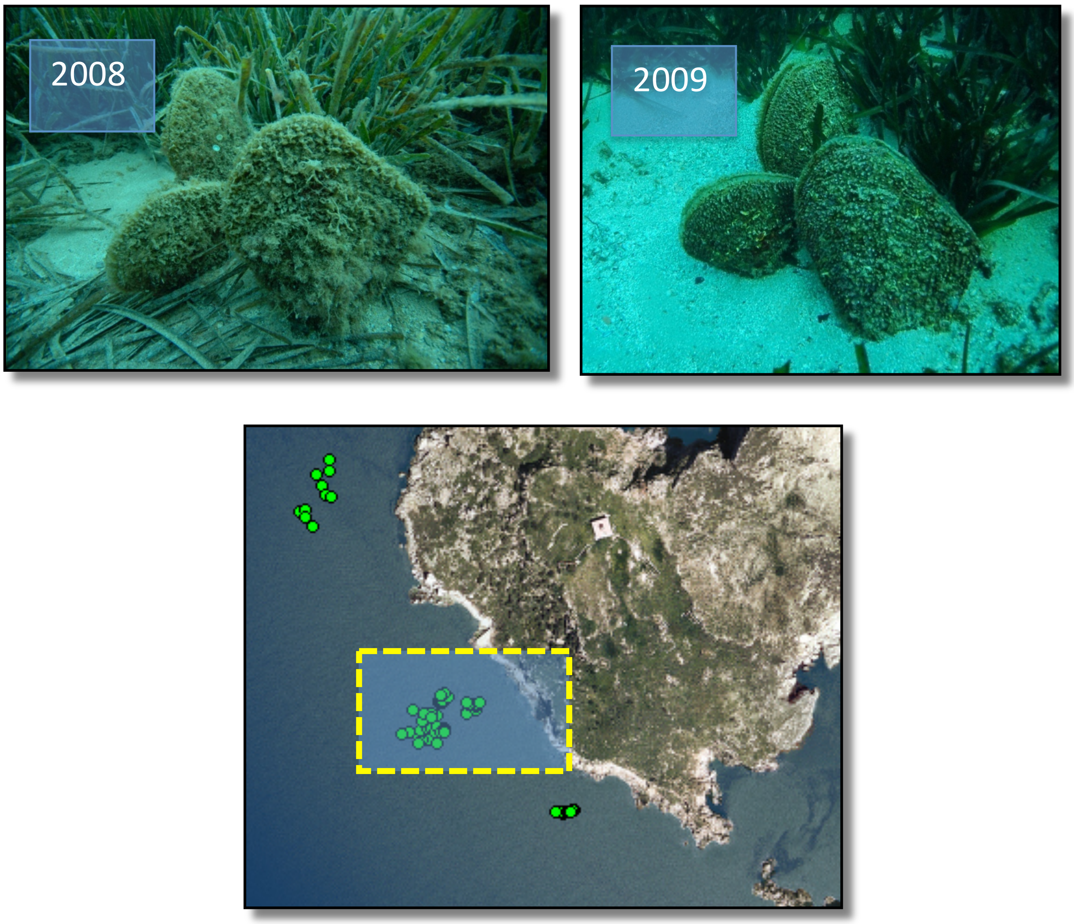
Vicente, N., Moreteau, J.C., Escoubet, P., 1980. Étude de l'évolution d'une population de Pinna nobilis L. (mollusque eulamellibranche) au large de l'anse de la Palud (Parc National sous-marin de Port-Cros). Trav scient Parc natn Port-Cros 6, 39-68.

Zavodnik, D., 1967. Contribution to the ecology of Pinna nobilis L. (Moll., Bivalvia) in the northern Adriatic. Thalassia Jugosl 3, 93–103.

Zavodnik, D., Hrs-Brenko, M., Legas, M., 1991. Synopsis on the fan shell Pinna nobilis L. in the eastern Adriatic Sea. Les Espèces Marines à Protéger en Méditerranée, Gis Posidonie Publ., Marseille, pp. 169–178.



Annex 1. Top: Images of buried and unburied shoots and rhizomes of *Posidonia oceanica* in the area Salpatxot (Medes Islands) where tens of individuals of *Pinna nobilis* were growing before the storm. Bottom: During the second survey in 2009, all individuals surveyed (dotted square) had been detached and sent away by the effects of the storm.



Annex 2. Top: Images of healthy individuals of fan mussel (*Pinna nobilis*) in the area Embarcador (Medes Islands). Bottom: During the second survey in 2009, all individuals surveyed (dotted square) were found intact.