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Patterns of algal recovery and small-scale effects of canopy removal as a result of human trampling on a Mediterranean rocky shallow community

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Abstract

The ecological importance of marine algae is widely known but in shallow coastal areas the composition and structure of algal communities may be affected by different human activities. Recovery from different trampling disturbances of two competing morphological groups (i.e. macroalgae and algal turfs) and effects of macroalgal canopy removal on the dominant associated fauna were examined using controlled trampling experiments. Six months after trampling disturbance was removed, the two morphological groups closely resembled control (untrampled) conditions, both in terms of cover and canopy (%). In particular, macroalgal recovery seemed to be very rapid: the higher the impact on the system the more rapid the recovery rate. In the short-term, the removal of macroalgal fronds (i.e. canopy) caused evident changes in invertebrate and crypto-benthic fish densities although these indirect effects were species-specific. Erect macroalgae are very sensitive to disturbance and even relatively low intensities of human use may be non-sustainable for this shallow assemblage. The present findings suggest some interesting options for the management of Mediterranean rocky shallow areas. This is crucial for coastal areas that are intended to be maintained in natural condition for conservation purposes.

Keywords: Marine algae; Trampling; Recovery; Canopy; Mediterranean Sea

1. Introduction

The ecological importance of marine algae is acknowledged worldwide (Hayward, 1980; Williams and Seed, 1992; Gee and Warwick, 1994; Hull, 1997; Chemello and Milazzo, 2002). In shallow coastal areas, besides natural disturbance (Paine and Levin, 1981; Sousa, 1984; Dayton et al., 1992), the composition and structure of algal communities may be affected by different human activities in both a direct and an indirect way (Addessi, 1994; Keough and Quinn, 1998; Lindberg et al., 1998).

The removal of erect macroalgae may affect the composition and structure of understorey assemblages modifying some physical factors (Reed and Foster, 1984; Duggins et al., 1990) thus playing an important role in several biological processes such as recruitment, competition and predation (Duggins et al., 1990; Benedetti-Cecchi and Cinelli, 1992; Underwood, 1998).

Assessing, interpreting and predicting these direct and indirect changes is essential to find tune conservation activities and environmental management (Benedetti-Cecchi et al., 2001).

Among all anthropogenic disturbances affecting natural populations and assemblages, in the last decades, human trampling on rocky shallow areas is receiving a growing interest by marine ecologists and conservation biologists and a large amount of literature has been recently produced (Woodland and Hooper, 1977; Beauchamp and Gowing, 1982; Liddle, 1991; Povey and Keough, 1991; Brosnan and Crumrine, 1994; Keough and Quinn, 1998; see also Milazzo et al., 2002b for review). Most of these studies highlighted cause–effect relationships through simulation, revealing that the vulnerability to human trampling depends mainly on the nature and morphology of marine algae and on the level of human use (Povey and Keough, 1991; Brosnan and Crumrine, 1994). Erect foliose algae are badly

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damaged by trampling (Keough and Quinn, 1998; Schiel and Taylor, 1999; Milazzo et al., 2002a), while algal turfs or low caespitose forms are more resistant showing an increase in cover when disturbance is intense (Brosnan and Crumrine, 1994; Schiel and Taylor, 1999). Similarly, the effects of human trampling on invertebrate species seems to be species-specific (i.e. related to their morphologies) and, in the case of mobile associated fauna, lasting in the short term (Povey and Keough, 1991; Brosnan and Crumrine, 1994; Brown and Taylor, 1999).

At present, the recovery of marine shallow communities from trampling disturbance has tended to receive less attention than the study of that from other anthropogenic impacts, particularly pollution (Southward and Southward, 1978; van Tamelen et al., 1997; Hawkins et al., 2002). Such studies are important in charting sustainable levels of use of rocky coasts by tourists and following legislation to manage this recreational activity (Thompson et al., 2002).

In Southern Australia, Povey and Keough (1991) demonstrated that the intertidal brown alga *Hormosira banksii* (Turner) Decaisne may need from 5 to 6 and up to 13 months to recover after impact has ceased, depending on trampling intensity.

The recovery from trampling of the small epifauna has been noted to be faster. After 3 months, density of turf-dwelling epifauna generally returns to control values (Brown and Taylor, 1999).

Very little is known on the indirect consequences of macroalgal canopy removal as a result of trampling (Milazzo et al., 2002a) on the other community species and there is some evidence for a strong dependence upon species behavior and scale of observation (Eckrich and Holmquist, 2000). For example, epibenthic fish abundance was observed to be less sensitive than grass shrimp to a decrease of seagrass structural complexity (Eckrich and Holmquist, 2000).

Few data are presently available for the Mediterranean Sea (Milazzo and Ramos-Esplá, 2000; Milazzo et al., 2002b). Manipulation experiments showed that the complete removal of *Cystoseira* species (the dominant macroalgae in the Mediterranean shallow waters), if consistent through time may lead to a dramatic change in the whole algal community, increasing the relative abundance of low complexity species like algal turfs (Benedetti-Cecchi and Cinelli, 1992) and thus lowering the entire community diversity. There is little evidence, however, whether these changes reflect the effect of anthropogenic disturbances in shallow marine communities (but see Benedetti-Cecchi et al., 2001). Only very recently, in the Ustica Island marine protected area (MPA), Milazzo et al. (2002a) showed that the direct impact of human trampling on erect macroalgae may be very substantial. The macroalgal species most affected by trampling were the canopy-forming brown algae *Cystoseira brachicarpa* J. Agardh v. *balearica* (Sauvageau) Giaccone and *Dictyota mediterranea* (Schiffner) G. Furnari. In that study, an experimental procedure was used comprising of increasing intensities of simulated trampling and a negative relation between algal coverage and human trampling levels was highlighted (Milazzo et al., 2002a).

However, from both a biological and a management point of view, the full effect of human trampling on marine shallow communities may be evaluated as a whole only accurately assessing (1) whether plant and animal assemblages recover after the impact, (2) whether there are persistent differences between different levels of use, and (3) whether indirect consequences affect the other community species (i.e. those not directly impacted by human trampling). For this reason, at the end of the simulation experiments carried out by Milazzo et al. (2002a), the trampled areas were monitored for a further period to determine whether assemblages recovered from trampling and whether indirect consequences of this recreational human activity occurred. In particular, the major aims of the present study were: (i) to assess the pattern of recovery from different trampling disturbances of two competing morphological groups (canopy macroalgae and algal turfs) and (ii) to determine the short-term effect of canopy algae removal on the dominant invertebrate species and crypto-benthic fishes associated to this rocky shallow community.

2. Methods

2.1. Study area

The study was carried out in the upper infralittoral zone (from 0.3 to 0.5 m depth) within the 'no-go zone' of the Ustica Island MPA (Zone A) (Fig. 1). This zone has been closed to the public since 1991, making it ideal for experimental study. The rocky shore along the 'no-go zone' is a flat basaltic platform and the seascape, up to 1.5 m depth, is characterized by a well-developed community of photophilic algae typical of non-polluted areas (Ros et al., 1984). Below this depth a barren habitat overgrazed by sea urchins takes place.

A detailed description of the algal species of the upper infralittoral (from 0.3 to 0.5 m depth) of the study area is reported in the Appendix. Destructive sampling was performed in May and August 2000 to determine the composition and structure of the algal assemblage.

Both in May and August 2000, the algal assemblage was dominated by the canopy-forming macroalgae *Cystoseira brachicarpa* v. *balearica* and *Dictyota mediterranea* (Milazzo et al., 2002a) (Appendix). A clear increment in the turf-forming species *Laurencia obtusa* (Hudson) Lamouroux percentage cover was evident from late May to late August (Milazzo et al., 2002a). In the latter month, the other species belonging to this

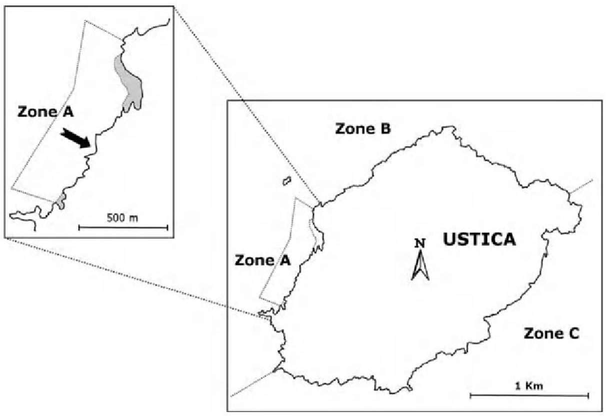

Fig. 1. The zonation of the Ustica Island MPA and the study area, namely Sbarramento (indicated by the black arrow). In grey the two bays heavily used by the Ustica Island MPA visitors.

group of algae were mainly the geniculate algae *Corallina granifera* Ellis et Solander and *Corallina officinalis* L., the finely branched *Stypocaulon scoparium* (Linnaeus) Kutzing, and the filamentous algae of the genus *Ceramium* (Appendix).

At this depth range, the most dominant macro-invertebrate species were the gastropod *Cerithium lividulum* Risso, 1826 and the hermit crab *Clibanarius erythropus* Latreille, 1818. The cnidarians *Anemonia sulcata* Pennant, 1777, *Balanophyllia europaea* (Risso, 1826), and *Cereus pedunculatus* (Pennant, 1777), the gastropods *Conus mediterraneus* Hwass in Bruguiére, 1792, and *Columbella rustica* Linnaeus, 1758, were also present (Milazzo, unpublished data). The tripterygid *Tripterygion tripteronotus* (Risso, 1810) was the most abundant crypto-benthic fish species (Milazzo, unpublished data).

2.2. Methodologies and experimental designs

2.2.1. Patterns of recovery from different trampling intensities

Algal recovery was assessed on experimental areas previously trampled by an operator at different intensities (0, 10, 25, 50, 100 and 150 passages) (but see Milazzo et al., 2002a for details). These trampling levels were assigned on the basis of the number of passages estimated to occur during the 2-month peak season at two bays heavily used by MPA visitors at the northern and southernmost limit of the 'no-go zone' of the reserve (Fig. 1).

The cover (%) and canopy (%) (sensu Brosnan and Crumrine, 1994) of canopy-forming macroalgae and algal turfs were determined two days after trampling and approximately every month from May to October 2000. Each month, five random and independent measurements of both variables were collected using a quadrat (0.09 m^2).

Algal recovery from different trampling intensities was evaluated using the three way ANOVA (Underwood, 1997), with Intensity (In) and Month (Mo) as fixed and orthogonal factors (6 levels each), and Area (Ar) nested in intensity as random factor (2 levels). Linear regressions on cover and canopy (%) data were used to examine trends across time (i.e. months) sampled at all trampling intensities.

The macroalgal recovery rates (i.e. the constant b of the cover/canopy vs. time linear regressions) were compared at each intensity using the slope test (Zar, 1994; Underwood, 1997).

2.2.2. Short-term effects of canopy removal on associated fauna

The effects of macroalgal canopy removal on small invertebrates and crypto-benthic fishes was investigated on four areas highly impacted by trampling (impact, $\geqslant$80% macroalgal canopy loss) and four controls (no impact, no canopy removal) at 0.3–0.5 m depth.

Density of the two most dominant invertebrate species (*Cerithium lividulum* and *Clibanarius erythropus*) was assessed by visual counts on 30×30 cm quadrats (10 replicates were considered), meanwhile underwater visual census (UVC) of crypto-benthic fish fauna was carried out along 0.4 m wide and 2 m long transects (four replicates).

Fish counts were performed by a skin-diver swimming slowly on the sampling area (covered in 5 min) (Harmelin, 1999). To achieve the independence of data collection, each replicate of the UVCs was performed in different days within each month.

Density of invertebrate and crypto-benthic fish was determined approximately every 4 weeks from May to July 2000.

Three way ANOVAs were used to test for the potential differences in both invertebrate and fish density between impacts (trampled areas with $\geqslant$80% macroalgal canopy loss) and controls (Underwood, 1997). The factors involved in the analyses were: Impact vs. Control (IC) as fixed and orthogonal factor (two levels), Month (Mo) fixed and orthogonal (three levels), and Area (Ar) random nested in IC (four levels).

Cochran's test was performed for all analyses to check for homogeneity of variances (Winer, 1971). When appropriate, SNK tests were employed to separate means (at $P = 0.05$). The GMAV 5.0 software (University of Sydney) was used to perform statistics.

3. Results

3.1. Patterns of algal recovery from different trampling intensities

3.1.1. Erect macroalgae

In the trampled areas at different intensities the erect macroalgae showed a marked recovery both in cover (%) and canopy (%) from simulated impact (Figs. 2 and 3). By contrast, in control areas (no passages) both variables showed on average minor variations from May to October 2000 (Figs. 2 and 3).

The three-way ANOVA clearly demonstrated that macroalgal recovery significantly differs among trampling intensities over the course of 6 months observation ($F_{25,288}=19.8$, $P<0.001$ for the algal cover, and $F_{25,288}=31.6$, $P<0.001$ for the algal canopy; Table 1). From May to July 2000 both variables displayed similar trends among different levels of disturbances (SNK test, Table 1), with lower values at an increasing impact. In September the macroalgal recovery was more evident since controls and mid-low trampling intensities (from 10 to 100 passages) showed similar values of coverage from one another (SNK test, Table 1). In October macroalgal cover and canopy did not exhibit any significant difference among trampling levels (from 0 to 150 passages) (SNK test, Table 1) and the recovery was complete.

The results of regression analyses on macroalgal cover and canopy (%) are reported in Table 2. For both variables the slope values (i.e. the coefficient b) revealed a clear increment at increasing trampling intensities (Table 2). For the macroalgal cover (%) the slope ranged from 0.3 to 12.4 (at 0 and 150 passages, respectively), and for the canopy (%) from −1.1 to 13.1 (again at 0 and 150 passages, respectively).

The slope pairwise comparisons of the macroalgal cover were significantly different between the trampled areas at low intensity (10 passages) and those trampled at more intense levels (from 25 to 150 passages), with these latter exhibiting a higher recovery rate from May to October 2000 (Table 2). Similarly, the canopy recovery rate was higher at 100 and 150 passages than at 10 passages (Table 2). Both variables significantly differed in the pairwise comparison between 150 and 25 passages (Table 2).

3.1.2. *Algal turfs*

From May to July algal turfs benefited from the reduced erect macroalgae coverage showing a rapid increase both in cover and canopy percentage (Figs. 4 and 5) and reaching their higher values (ranging on average among 40–60%) in the heavily trampled areas. Just 3 months after trampling ceased, both variables

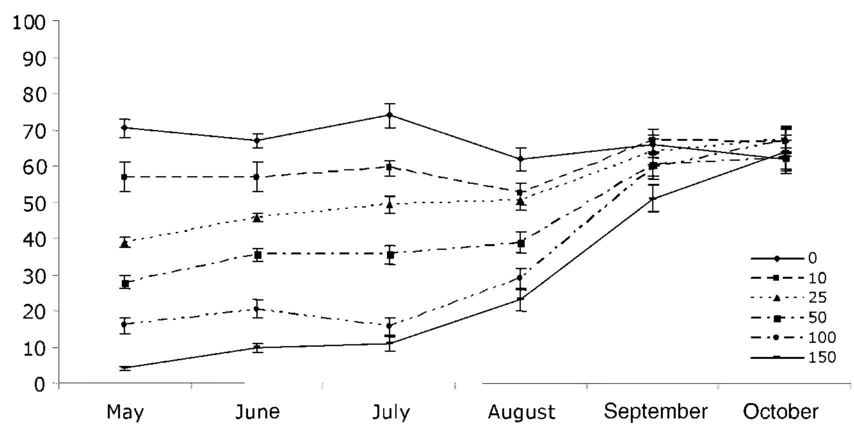

Fig. 2. Average (±S.E.) macroalgal cover (%) at different trampling intensities (no. of passages) from May to October 2000.

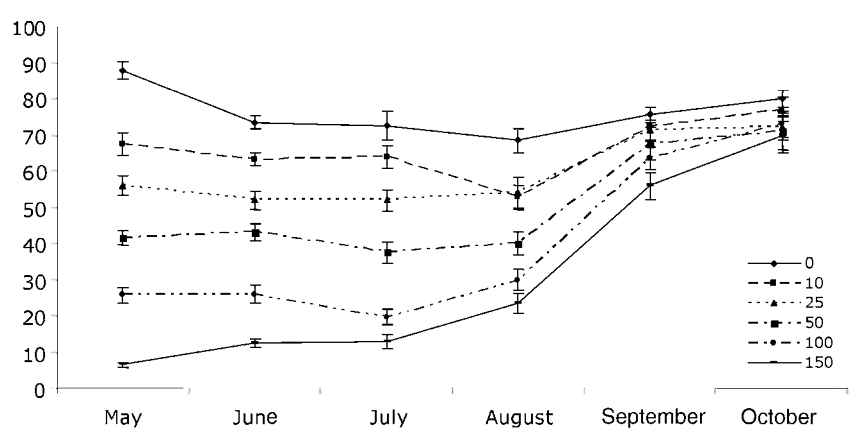

Fig. 3. Average (±S.E.) macroalgal canopy (%) at different trampling intensities (no. of passages) from May to October 2000.

started to decrease attaining in October very low values at all intensities (about 10–15%) (Figs. 4 and 5).

The analyses of variance confirmed that the differences between trampled areas at different intensities were highly significant during the 6-month study (the interaction In × Mo is significant; $F_{25,288} = 11.7$, $P < 0.001$ for the turf cover, and $F_{25,288} = 11.7$, $P < 0.001$ for the turf canopy; Table 3). Two days after trampling experiments (May 2000) algal turfs were not significantly dependent on intensities (SNK test, Table 3). Generally, from June to August, the algal turf cover and canopy recorded at mid-high intensities of trampling were higher than those recorded in controls and in low impacted areas (10 passages). In September both variables further decreased showing significant differences between trampled areas and controls (SNK test, Table 3). At the end of the observations, again the algal turf cover and canopy were not significantly different at a range of trampling intensities (SNK test, Table 3).

3.2. Short-term effects of canopy removal on associated fauna

3.2.1. Invertebrates

From May to July, the density of the gastropod *Cerithium lividulum* was not significantly different between impacts and controls (the interaction IC × Mo was not significant; Table 4). Density values ranged on the average from 1.3 (±0.7 S.E.) to 1.7 (±0.9 S.E.) individuals/0.09 m^2 (Fig. 6) and strongly varied in space (Ar(IC), $F_{6,216}$, $P < 0.01$; Table 4).

In contrast, *Clibanarius erythropus* density (Fig. 6) was affected by the loss of the macroalgal canopy (IC×Mo, $F_{2,216} = 1.21$, $P < 0.05$; Table 4) and this pattern seemed to be constant in space [Ar(IC) was not significant; Table 4]. However, the response of *Clibanarius erythropus* to canopy reduction was evident only in July, 2 months after trampling ceased (Fig. 6 but see SNK test; Table 4).

3.2.2. Benthic fish fauna

Only two species of crypto-benthic fish were censused along this study in the impacted and control areas: the tripterygid *Tripterygion tripteronotus* and the gobid *Gobius bucchichi* Steindachner, 1870.

On average the density of *Tripterygion tripteronotus* in areas with low macroalgal canopy (IMP) is constant through time (about 1.5 ind./0.8 m^2) (Mo was not significant), slightly decreasing in control areas (CTL) during the 3 months of observation (Fig. 7). Significant differences between impacts and controls were evident (IC, $F_{1,72} = 6.39$, $P < 0.05$; Table 5).

A different pattern is showed by the analysis of the *Gobius bucchichi* density. In impacted areas, average density was constant during the first 2 months of observation (0.7±0.3 S.E. in May and 0.8±0.4 S.E. in June), decreasing to values near to zero in July (Fig. 7). From May to July, this gobid species was absent in control areas with a high algal canopy (Fig. 7).

Table 1
Analysis of variance on macroalgal cover and canopy from May to October 2000 at different trampling intensities

ANOVA					
		Erect macroagae			
		Cover%		Canopy%	
Source of variation	*df*	MS	*F*	MS	*F*
Intensity: In	5	14,907.7	86.8***	17,540.9	66.3***
Month: Mo	5	10,168.4	212.5***	10,851.9	312.0***
Area: Ar(In)	6	171.7	1.7ns	264.6	2.92**
In × Mo	25	946.8	19.8***	1098.9	31.6***
Mo × Ar(In)	30	47.8	0.49ns	34.8	0.38ns
Residuals	288	98.6		90.6	
Transformation		none		none	
Cochran test		$C = 0.04$; $P > 0.05$		$C = 0.03$; $P > 0.05$	
SNK test (interaction In × Mo)		S.E. = 2.18; *df* = 30		S.E.: 1.84; *df* = 30	
May		0 > 10 > 25 > 50 > 100 > 150		0 > 10 > 25 > 50 > 100 > 150	
June		0 > 10 > 25 > 50 > 100 > 150		0 > 10 > 25 > 50 > 100 > 150	
July		0 > 10 > 25 > 50 > 100 = 150		0 > 10 > 25 > 50 > 100 > 150	
August		0 > 10 = 25 > 50 > 100 = 150		0 > 10 = 25 > 50 > 100 > 150	
September		0 = 10 = 25 = 50 = 100 > 150		0 = 10 = 25 = 50 = 100 > 150	
October		0 = 10 = 25 = 50 = 100 = 150		0 = 10 = 25 = 50 = 100 = 150	

ns, not significant. ** $P < 0.01$. *** $P < 0.001$.

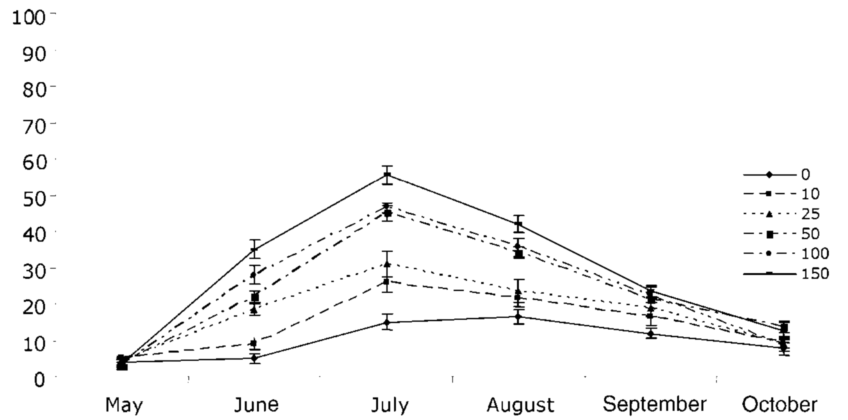

Fig. 4. Average (±S.E.) algal turf cover (%) at different trampling intensities (no. of passages) from May to October 2000.

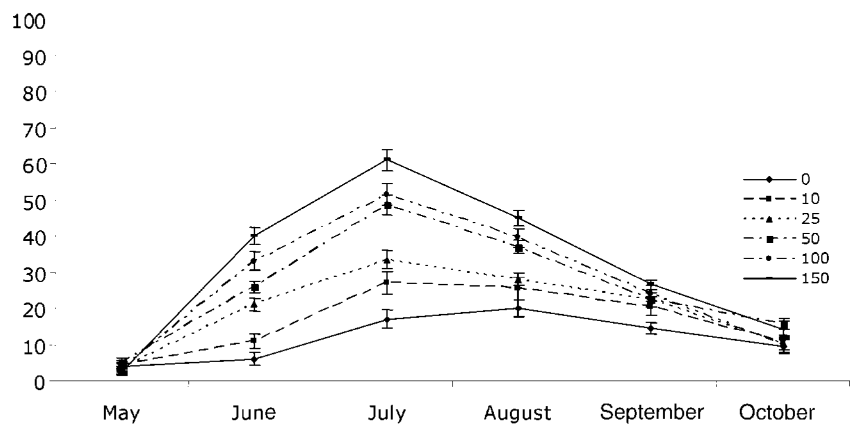

Fig. 5. Average (±S.E.) algal turf canopy (%) at different trampling intensities (no. of passages) from May to October 2000.

Analysis of variance confirmed that the differences between impacted and control areas were highly significant during the 3-month study (IC × Mo, $F_{2,72}=8.95$, $P<0.01$; Table 5), showing a positive interaction of macroalgal canopy reduction with the density of this species especially in the first two months (SNK test; Table 5).

4. Discussion

Erect macroalgae, important structural species (or habitat formers, *sensu* Reed and Foster, 1984) in both intertidal and subtidal habitats (Dayton, 1985, Duggins and Dethier, 1985; Benedetti-Cecchi and Cinelli, 1992), are very sensitive to human trampling and even relatively low intensities of human use may be non-sustainable for this assemblage (Povey and Keough, 1991; Brosnan and Crumrine, 1994; Keough and Quinn, 1998; Schiel and Taylor, 1999; Milazzo et al., 2002a).

The results of the present study clearly show that the responses to direct (i.e. trampling) or indirect (i.e. canopy reduction) disturbances are species-specific for both algal species and associated fauna.

The study of algal recovery after pulse trampling (i.e. a periodic disturbance) rather than a press trampling (i.e. a chronic disturbance) was preferred due to its similarity to real human pressure occurring in several Mediterranean rocky coastal areas, including Ustica Island, where the impact of tourist activities is somewhat limited to July and August (Badalamenti et al., 2000; Milazzo and Ramos-Esplá, 2000).

A direct relationship between levels of human use and the macroalgal recovery rate is very clear, as highlighted by a pairwise comparison of the linear regression slopes. In general, macroalgae of low impacted areas (10 and 25 pedestrian passages) seem to recover slower than those belonging to areas where the level of damage is higher (100 and 150 pedestrian passages).

Algal turfs were more resistant than erect macroalgae to disturbance, very likely because of their low profile morphology, which has been found to make plants less vulnerable to trampling (Liddle, 1991). This is in agreement with similar studies carried out in the United States and Australia, revealing a great resistance of turf forms to intense trampling (Brosnan and Crumrine, 1994; Schiel and Taylor, 1999). As shown by the general increase in cover and canopy from May to July 2000

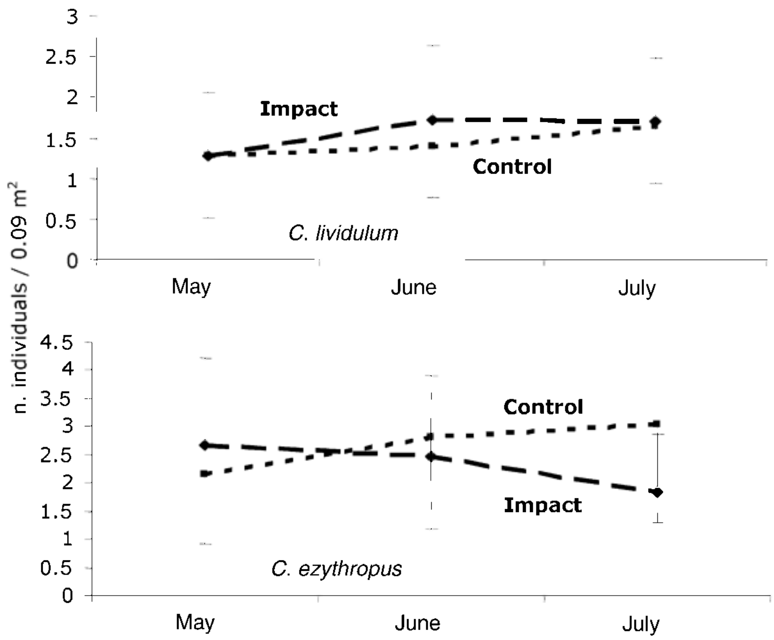

Fig. 6. Average (±S.E.) density of invertebrate species between impacted and control areas from May to July 2000.

Table 2
Regression analyses (*a* is not reported) and slope pairwise comparisons (F values and level of significance) on macroalgal cover/canopy vs. months at different intensities of trampling ($n = 60$). Dependent variables: cover (%)/canopy (%); independent variable: month

Linear regressions

Intensity	Cover (%)			Canopy (%)		
	b	*r*	*p*	*b*	*r*	*p*
0	0.3	0.06	n.s.	−1.1	0.18	n.s.
10	2.1	0.30	*	1.8	0.26	*
25	5.6	0.71	***	4.0	0.53	***
50	7.2	0.73	***	6.4	0.65	***
100	11.0	0.84	***	10.3	0.78	***
150	12.4	0.88	***	13.1	0.89	***

Slope pairwise comparisons

Intensity	10	25	50	100	150	
10	–	0.75ns	2.12ns	5.03*	11.96**	
25	6.99*	–	0.67ns	3.08ns	9.06*	
50	7.98*	0.93ns	–	0.93ns	3.61ns	Canopy (%)
100	9.81*	3.88ns	1.66ns	–	0.48ns	
150	7.77**	8.72*	4.10ns	0.17ns	–	
			Cover (%)			

Cochran test was not significant in each partial analysis. n.s. (not significant). $*P<0.05$. $**P<0.01$. $***P<0.001$.

both, in trampled and control areas, in the Ustica Island MPA, seasonal changes and the reduction of macroalgal species appeared to be more important in affecting algal turfs coverage rather than human trampling disturbance.

In the Mediterranean Sea, the removal of canopy algae often results in a rapid colonization of space by stands of turf-forming algae (Benedetti-Cecchi and Cinelli, 1992; Benedetti-Cecchi et al., 1996, 2001). Furthermore, a dense mat of turf resulting from an intense anthropogenic disturbance (such as chronic human trampling; Brosnan and Crumrine, 1994; but see Keough and Quinn, 1998) may drastically inhibit the recruitment of the erect macroalgae (as *Cystoseira* spp.) (Benedetti-Cecchi and Cinelli, 1996). This effect was consistent through time (Benedetti-Cecchi et al., 2001). However, this was not observed in the present case, since erect macroalgae of the shallow waters of Ustica Island thrived, completely recovering 6 months after disturbance when the impact was removed.

By contrast, 6 months after impact, the algal turf coverage in the trampled areas were no longer significantly different from that of the control areas. This demonstrated a return to a structural state typical of pristine areas: a well-developed community of photophilic algae forming a multi-layered and spatially complex disposition of algal species (Ros et al., 1984).

At present, very little is known about the recovery of algal assemblages from disturbance. Most of published studies deal with the responses of intertidal algal species to natural and anthropogenic events, such as storms, oil spills and ice scouring (Southward and Southward, 1978; McCook and Chapman, 1991, 1997; van Tamelen et al., 1997) and to experimental simulations (Jenkins et al., 1999a,b). More recently some authors have shown that the amount of damage is the primary factor for recovery (Underwood, 1998; Speidel et al., 2001). *Fucus gardneri* (Silva) recovery has been shown to be similar for canopy reductions of up to 80% (about 12 months), but the complete removal treatment (100% of canopy and holdfast removed) delayed its recovery by several months (Speidel et al., 2001). Similarly, *Hormosira banksii* canopy was shown to quickly recover if fronds were removed by disturbance, but where holdfasts were also removed the recovery was slow (Underwood, 1998). At Ustica Island, visual inspection of the trampled areas showed that recovery occurred through regeneration from holdfasts, rather than by recruitment of young plants (see Povey and Keough, 1991; Milazzo et al., 2002a). During trampling, the algal holdfasts were stepped on but not detached from the substrate. At high trampling intensities, the holdfasts were not damaged (or were not damaged severely) allowing the plants to re-grow quickly.

In shallow water habitats, patterns are likely to be generated by direct as well as indirect interactions (Benedetti-Cecchi, 2000), and, as we have seen before, an indirect consequences of human trampling is clearly the removal/reduction of the macroalgal canopy.

During the 3 month observation, macroalgal canopy removal/reduction did not show any marked consequence on the density of the gastropod *Cerithium lividulum*. On the contrary, the hermit crab *Clibanarius erythropus* showed a significant decrease. In July, macroalgal canopy was approximately 20%, while algal turf canopy reached more than 50%. In control areas,

Table 3
Analysis of variance on algal turf cover and canopy from May to October 2000 at different trampling intensities

ANOVA		Algal turf			
		Cover %		Canopy %	
Source of variation	*df*	MS	*F*	MS	*F*
Intensity: In	5	2834.1	68.2***	3194.3	38.8***
Month: Mo	5	8469.3	440.1***	10403.3	255.2***
Area: Ar(In)	6	41.5	0.9ns	82.3	1.6ns
In × Mo	25	385.3	20.1***	476.9	11.7***
Mo × Ar(In)	30	19.2	0.4ns	40.8	0.8ns
Residuals	288	44.5		51.3	
Transformation		None		None	
Cochran test		$C=0.04$; $P>0.05$		$C=0.05$; $P>0.05$	
SNK test (interaction In × Mo)		s.e. = 1.38; df = 30		s.e. = 2.01; df = 30	
May		0 = 10 = 25 = 50 = 100 = 150		0 = 10 = 25 = 50 = 100 = 150	
June		0 < 10 < 25 = 50 < 100 = 150		0 = 10 < 25 = 50 < 100 < 150	
July		0 < 10 < 25 < 50 = 100 < 150		0 < 10 < 25 < 50 = 100 < 150	
August		0 < 10 = 25 < 50 = 100 < 150		0 = 10 = 25 < 50 = 100 = 150	
September		0 < 10 = 25 = 50 = 100 < 150		0 < 10 = 25 = 50 = 100 = 150	
October		0 = 10 = 25 = 50 = 100 = 150		0 = 10 = 25 = 50 = 100 = 150	

ns, not significant. ***$P<0.001$.

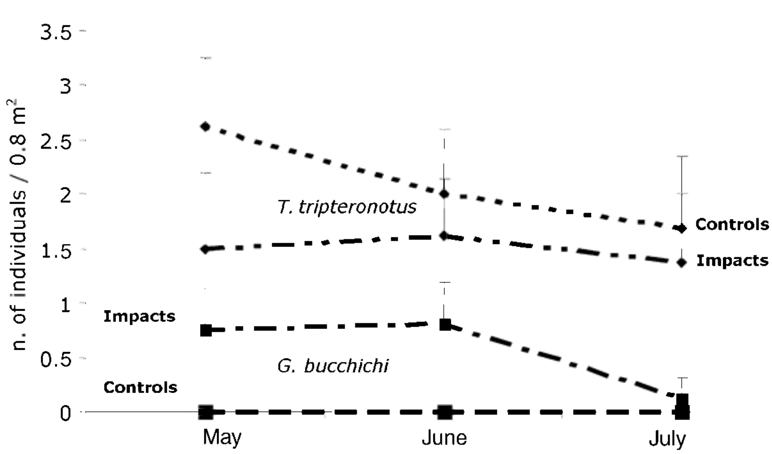

Fig. 7. Average (±S.E.) density of crypto-benthic fish species between impacted and control areas from May to July 2000.

Table 4
Analysis of variance on invertebrates density between impacted (IMP) and Control (CTL) areas from May to October 2000

ANOVA					
		Invertebrates			
		Cerithium lividulum		*Clibanarius erythropus*	
Source of variation	*df*	*MS*	*F*	*MS*	*F*
IMP vs. CTL: IC	1	0.93	0.16ns	0.22	0.51ns
Month: Mo	2	3.40	1.79ns	0.25	1.07ns
Area: Ar(IC)	6	5.76	3.44**	0.42	1.38ns
IC × Mo	2	0.61	0.32ns	1.21	5.2*
Mo × Ar(IC)	12	1.89	1.13ns	0.23	0.75ns
Residuals	216	1.67		0.31	
Transformation		None		$\ln(X+1)$	
Cochran test		$C=0.08$; $P>0.05$		$C=0.11$; $P>0.05$	

SNK test	*Clibanarius erythropus*
May	IMP = CTL
June	IMP = CTL
July	IMP < CTL
Impact (IMP)	May = June > July
Control (CTL)	May = June = July

ns, not significant. $*P<0.05$. $**P<0.01$.

the hermit crab density was constant as were both macroalgal and algal turf canopies.

Previous studies revealed that increases in invertebrate density (in particular of herbivores), generally occurring sometime after macroalgal canopy/cover reduction (Underwood, 1998), may be attributed to an indirect effect of trampling (Keough and Quinn, 1998). No data are presently available in the literature on the slow indirect effects of trampling (i.e. decrease of the abundance) on hermit crabs and very little is known on their feeding habits. Although further investigation is still needed (i.e. studies on the biology and feeding ecology of *Clibanarius erythropus*) it is possible that there is an inverse relationship between the presence of turf forms and the density of hermit crabs, rather than a slow response of this species to canopy removal or human trampling.

The comparison between impacted and control transects revealed a slight susceptibility of the benthic fish *Tripterygion tripteronotus* to macroalgal canopy removal. As confirmed by data available in the literature, *T. tripteronotus* shows a preference for habitat dominated by canopy forming algae (Tortonese, 1975) which provide both a high amount of food (i.e. small invertebrate species such as molluscs, polychaetes, amphipods and copepods) and shelter from predators (mainly piscivorous fishes) (see Garcia-Charton et al., 2000; Milazzo et al., 2000; Chemello and Milazzo, 2002).

On the other hand, abundance of *Gobius bucchichi* was increased by the reduction of the macroalgal canopy. The response of this species was very swift. Significant differences between impacted and control areas were evident in May (only 2 days after the impact) and June. More than 2 months after trampling (in July), when the erect macroalgae started to recover and the algal turf canopy was very high, the densities among treatments were comparable with one another.

These results were similar to what is reported on the effects of seagrass canopy removal both from the Mediterranean Sea and elsewhere (Eckrich and Holmquist, 2000; Guidetti and Bussotti, 2002).

The density of gobid species increased in trampled plots, where the seagrass canopy was low, while an opposite trend was generally evident for the nectobenthic fishes (Eckrich and Holmquist, 2000). Guidetti and Bussotti (2002) provided evidence of this inverse relationship between *G. bucchichi* and the canopy (i.e. removed patches of seagrass and sand habitat).

This indicates that canopy removal by human trampling may have an effect on the composition of the crypto-benthic fish assemblage. Although this was not our case, we would expect that a sustained trampling for a longer period may cause a rapid decline in macroalgal cover, leading the shallow community to a simpler structural state dominated by very low profile and turfing-form algae. Indirectly, this could have had an effect

Table 5
Analysis of variance on crypto-benthic fish density between impacted (IMP) and Control (CTL) areas from May to October 2000

ANOVA					
		Crypto-benthic fishes			
		Tripterygion tripteronotus		*Gobius bucchichi*	
Source of variation	*df*	*MS*	*F*	*MS*	*F*
IMP vs. CTL: IC	1	8.76	6.39*	3.21	83.4***
Month: Mo	2	2.26	2.95ns	0.47	8.95**
Area: Ar(IC)	6	1.37	1.13ns	0.04	0.58ns
IC × Mo	2	1.63	2.13ns	0.47	8.95**
Mo × Ar(IC)	12	0.76	0.63ns	0.05	0.79ns
Residuals	72	1.21		0.07	
Transformation		None		ln($x+1$)	
Cochran test		$C=0.10$; $p>0.05$		$C=0.19$; $p>0.05$	

	Gobius bucchichi
SNK test (interaction IN × Mo) S.E. = 0.8; *df* = 12	
May	IMP > CTL
June	IMP > CTL
July	IMP = CTL
Impact (IMP)	May = June > July
Control (CTL)	May = June = July

ns, not significant. *$P<0.05$. **$P<0.01$. ***$P<0.001$.

on the benthic fish fauna, decreasing the abundance of *Tripterygion tripteronotus*, meanwhile enhancing that of *Gobius bucchichi*.

The present study, the first of this type in the Mediterranean Sea, may have implications for marine conservation but also for environmental impact monitoring, representing a first effort for the correct identification and comprehension of the direct and indirect consequences of human trampling on Mediterranean rocky shallow areas. The most important implication for monitoring and conservation was the difference in both the direct and indirect responses of marine organisms to human disturbance.

We were able to examine the effects of trampling on only one spatial and temporal scale. We used this small scale mainly for ethical reasons since we were unwilling to trample large areas of one of the few effectively protected sections of rocky shore in Italy (Badalamenti et al., 2000).

Although the present information is still insufficient to depict more general conclusions, the integration of these findings with similar studies that should be performed in other Mediterranean areas may suggest interesting options for the correct management of human recreational activities and could be helpful for future studies at larger scales. This is particularly crucial for coastal areas that are intended to be maintained in natural condition for conservation purposes, such as Mediterranean MPAs (Badalamenti et al., 2000), where the increasing number of tourists may represent a severe threat to shallow communities (Milazzo et al., 2002b). In some over-frequented areas this problem has been overcome by the construction of raised boardwalks (Carlson and Godfrey, 1989; Liddle, 1991). According to the management solutions proposed by Keough and Quinn (1998), in Mediterranean coastal areas it could be sufficient to rotate zones, opening some to visitors and closing others, rather than deploying raised boardwalks that may exert both a visual and biological impact (see Kelaher et al., 1998). Thus, the intervals between two 'open access' should guarantee a complete recovery of the biotic components of the system such as that of the erect macroalgae.

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Appendix A. List of the algal species collected by destructive sampling within the 'no-go zone' of the Ustica Island MPA in May and August 2000

Rhodophyta

Amphiroa rigida Lamouroux
Bangia atropurpurea (Roth) C. Agardh
Boergeseniella fruticulosa (Wulfen) Kylin
Ceramium circinatum (Kutzing) J. Agardh
Ceramium flaccidum (Kutzing) Ardissone
Ceramium tenerrimum (G. Martens) Okamura
Ceramium tenuissimum (Lyngbye) J. Agardh
Chylocladia verticillata (Lightfoot) Bliding
Corallina granifera Ellis et Solander
Corallina officinalis L.
Dasya rigidula (Kutzing) Ardissone
Dermatolithon cystoseirae (Hauck) Huvé
Dipterosiphonia rigens (Schousboe) Falkenberg
Erythrocystis montagnei (Derbés and Solier) Silva
Erythrotrichia carnea (Dillwyn) J. Agardh
Falkenbergia rufolanosa (Harvey)
Fosliella sp.
Gelidium sp.
Griffithsia sp.
Herposiphonia secunda (C. Agardh) Ambronn f. *tenella* (C. Agardh) Wynne
Jania rubens (L.) Lamouroux
Laurencia obtusa (Hudson) Lamouroux
Lophosiphonia cristata Falkenberg
Lophosiphonia subadunca (Kutzing) Falkenberg
Melobesia membranacea (Esper) Lamouroux
Phymatolithon lenormandii (Areschoug) Adey
Polysiphonia elongata (Hudson) Sprengel
Polysiphonia sp.
Stylonema alsidii (Zanardini) Drew
Wrangelia penicillata (C. Agardh) C. Agardh

Phaeophyta

Cystoseira brachycarpa J. Agardh v. *balearica* (Sauvageau) Giaccone
Dictyota dichotoma (Hudson) Lamouroux v. *dichotoma*
Dictyota mediterranea (Schiffner) G. Furnari
Dictyota sp.
Halopteris filicina (Grateloup) Kutzing
Lobophora variegata (Lamouroux) Womersley
Padina pavonica (L.) Lamouroux
Sphacelaria cirrosa (Roth) C. Agardh
Sphacelaria fusca (Hudson) Gray
Stypocaulon scoparium (L.) Kutzing

Clorophyta

Anadyomene stellata (Wulfen) C. Agardh
Cladophora sp.
Halimeda tuna (Ellis and Solander) Lamouroux
Pseudochlorodesmis furcellata (Zanardini) Boergesen v. *furcellata*
Valonia utricularis (Roth) C. Agardh
Acetabularia acetabulum (L.) Silva

Cyanophyta

Calothrix sp.

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