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Desertification of Mediterranean rocky reefs caused by date-mussel, *Lithophaga lithophaga* (Mollusca: Bivalvia), fishery: effects on adult and juvenile abundance of a temperate fish

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Abstract

Macroalgal beds in temperate rocky habitats provide shelter and food for many adult reef fishes and their juvenile stages. In the Mediterranean Sea, the fishery of the endolithic date-mussel *Lithophaga lithophaga* (which involves dismantling of rocky substrates inhabited by these bivalves) may cause formation of barrens in shallow rocky reefs. Preliminary data collected in SW Apulia (SE Italy) show that rocky reefs impacted by this destructive fishery display different distribution patterns of adult *Coris julis* (a common labrid fish in the Mediterranean basin), and lower abundance of juveniles. The ecological implications of date-mussel fishery for dynamics of fish populations and rocky-reef ecosystem functioning (e.g., nursery role) are discussed.

Keywords: Rocky-reef fish; Fish recruitment; Date-mussel fishery; Human impact; Mediterranean Sea

1. Introduction

It is well known that rocky reefs in many temperate regions support large stands of macroalgae which, together with sessile animals and topographic features, increase habitat complexity (Turner et al., 1999). Due to their sizeable physical structure and productivity, rocky-algal habitats may provide refuge against predators, and food for adults and juveniles of many reef fishes (Holbrook et al., 1990; Garcìa-Rubies and Macpherson, 1995; Levin and Hay, 2002). Macroalgal cover in rocky reefs may vary in space and time due to both natural variations and anthropogenic disturbances (Dayton, 1985), and such spatio-temporal variations may reflect in dramatic changes in the associated fish assemblages (Carr, 1994; Levin and Hay, 2002).

The European date-mussel, *Lithophaga lithophaga*, is an endolithic bivalve living inside carbonatic rocks (limestone). Collection of these bivalves, which involves breaking of rocks (and consequent heavy damages to rocky reefs), has been formally banned in the last decades in many countries along the Mediterranean. In some areas of southern Italy, but also in other areas of the Mediterranean (Fanelli et al., 1994 and references), nevertheless, the date-mussel fishery (hereafter DMF) is still practiced. Poachers, usually equipped with SCUBA, underwater vehicles and special sledgehammers, systematically break rocky substrates to collect the molluscs. Besides direct damage to benthic assemblages (i.e., rock dismantling, and eradication of sessile animals and algae), there is more and more evidence that intense DMF may cause a significant increase in sea urchin density and biomass (Guidetti et al., 2003). The consequent sea urchin overgrazing seems to be capable of enlarging bare patches caused by DMF, and of causing formation of barren areas for many years (Fanelli et al., 1994; Fraschetti et al., 2001; Guidetti et al., 2003). Average cover of 'barrens' has been reported to range between about 80% and 95% in rocky reefs heavily impacted by DMF, whereas it seldom exceeds 10% in rocky reefs unaffected by DMF (Guidetti et al., 2003). Taking into account that in the Mediterranean Sea several fish species are associated with rocky reefs covered by erected macroalgae (Garcìa-Rubies and Macpherson, 1995; Guidetti, 2000; Ruitton et al., 2000), Guidetti et al. (2002, 2004) suggested that the desertification caused by DMF could explain the differences in

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the structure of adult fish assemblages observed between reefs impacted by DMF and controls (i.e., rocky reefs with flourishing macroalgal beds). At present, conversely, there are no data about the possible effects of desertification by DMF on the abundance of juvenile stages of fish.

Coris julis is a common small labrid fish that lives in several coastal habitats in the Mediterranean, such as rocky reefs, seagrasses, and to a lesser extent on coarse sand, often in the nearby of vegetated habitats or rocks (Tortonese, 1975). As with many other labrids, juveniles and adults of this species live in the same habitats (Garcìa-Rubies and Macpherson, 1995). In shallow rocky reefs, juveniles are mainly associated with macroalgal beds where, similarly to adults, they feed upon small invertebrates and take refuge against predators.

This note examines the putative DMF impact on the abundance patterns of adults and juveniles of *C. julis*, here used as a model, in shallow Mediterranean rocky reefs.

2. Materials and methods

Sampling was carried out at four locations (2–3 km apart from each other) along the SW Apulian coast (Ionian Sea, SE Italy; Fig. 1). The sampling area is characterised by calcareous medium-sloped rocky plateaus, dropping over sand at about 10–15 m depth. The two impacted locations (La Strea and S. Isidoro, hereafter F1 and F2) were characterised by an almost complete absence of macroscopic sessile organisms, except for rare and sparse patches formed by colonies of the sponge *Chondrilla nucula* and some macroalgae (e.g., *Dictyota* spp.). The two control locations (Paritone and Porto Selvaggio, thereafter C1 and C2), instead, showed similar environmental features (e.g., slope, wave exposure), but flourishing macroalgal canopies mainly consisting of Dictyotales, articulated Corallinaceae and *Cystoseira* sp. Underwater visual censuses of both juvenile and adult *C. julis* were performed at about 5 m depth, along 25 m long and 5 m wide transects (Guidetti et al., 2002 and references). At each location, three sites (200–300 m apart) were randomly selected, and three visual censuses were carried out at each site. Sampling was repeated in three dates during August 2000 (when settlement of *C. julis* usually takes place; Garcìa-Rubies and Macpherson, 1995), and the average of each series of three censuses (i.e., performed on each sampling date) has been used as a replicate. According to Garcìa-Charton and Pérez-Ruzafa (2001), this procedure should be preferred to 'snap-shot' sampling in order to reduce the effects of stochastic short-time variations, typical of mobile species, this making much more robust estimates of mean density of fish. Analysis of variance (GMAV5; University of Sydney, Australia) was used to test for putative differences in density of *C. julis* (adults and juveniles) in relation to the DMF impact level (present/absent), among locations, and among sites within locations. The factor 'DMF' was considered fixed in the analyses, 'Location' was random and nested within 'DMF', and 'Site' was random and nested within 'Location'. The overall residual has been partitioned into the residual of the impacted locations, and that of controls. A 2-tailed F-test was used to test whether the impact affected fish density at the spatial scale of replicates. These terms have also been used, when appropriate, as denominators to test for $S(F)$ and $S(\mathrm{Cs})$, respectively. Whenever $S(F)$ or $S(\mathrm{Cs})$ was significant and the other not (see Section 3), this has been interpreted as an evidence of the impact at the scale of sites between the impacted location and the controls. Prior to analysis, the homogeneity of variance was tested by Cochran's test (Underwood, 1997).

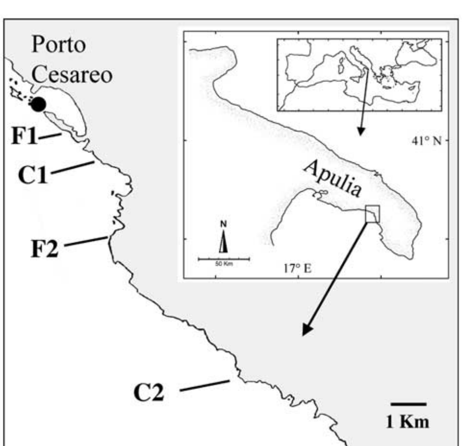

Fig. 1. Map of the sampling area: F1 (La Strea) and F2 (S. Isidoro) = locations impacted by DMF; C1 (Paritone) and C2 (Porto Selvaggio) = controls.

3. Results and discussion

The results of ANOVA testing for effects of DMF on adult and juvenile density of *C. julis* are summarised in Table 1. Adult fish density (Fig. 2) generally ranged between 3 and 17 individuals 125 m^{-2} at the controls, and between 4 and 18 ind. 125 m^{-2} at the DMF impacted locations. Statistical analysis did not reveal any significant difference in mean density attributable to the impact. Significant variability, instead, was detected between locations (i.e., at the scale of kilometres) within each level of DMF impact, and among sites (i.e., at the scale of hundreds metres) only within the impacted locations. Juvenile *C. julis* density (Fig. 2) varied from 2 to 12 ind. 125 m^{-2} at the control locations, and from 0 to 4 ind. 125 m^{-2} at the locations affected by DMF.

Table 1
ANOVAs testing for differences in *C. julis* density (adults and juveniles) related to the DMF impact, at different spatial scales

Source	d.f.	Adults		Juveniles	
		MS	F	MS	F
DMF = F	1	1.78	0.02 ns	200.69	425.00**
Location = $L(F)$	2	102.78	6.14*	0.47	0.05 ns
Site = $S(L(F))$	8	16.75	2.78*	9.00	2.61*
$S(F)$	4	18.25	3.03*	16.72	3.07*
S(Cs)	4	15.28	2.54 ns	1.30	0.93 ns
Residual	24	6.02		3.44	
Res(F)	12	7.00		5.44	
Res(Cs)	12	5.06		1.40	
2-Tailed F-test					
Replicates		0.59 ns			12.84*
Sites		–			–
Cochran's test			0.28 ns		0.23 ns
Transform			None		None

Significance levels: ns = $p > 0.05$; $* = p < 0.05$; $** = p > 0.01$.

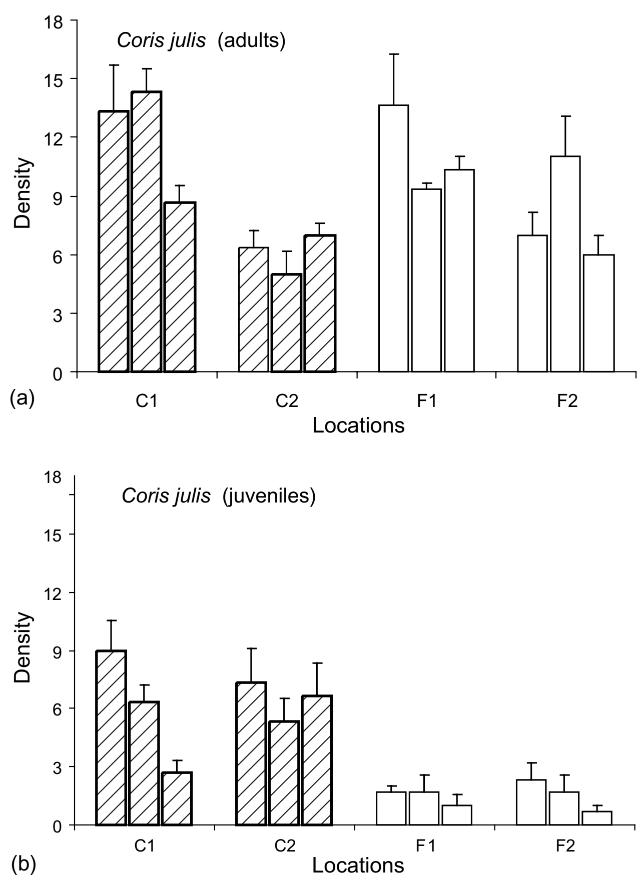

Fig. 2. Mean (±SE) density (no. individuals 125 m^{-2}) of *C. julis* (adults and juveniles) at three sites from the two controls (C1 and C2) and the two locations impacted by DMF (F1 and F2).

ANOVA detected a significantly greater density of juvenile *C. julis* at the controls than at the impacted locations. Significant differences in the distribution patterns of juvenile *C. julis*, moreover, were detected among replicates within the impacted sites (i.e., at the scale of tens metres; as shown by the significant 2-tailed test) and among sites at the impacted locations, whereas no differences were observed at the spatial scale of locations, or at the scale of sites at the controls.

The present study provides evidence that desertification caused by DMF could have the potential to affect distribution patterns of adult *C. julis*, and the abundance of juveniles, in shallow Mediterranean rocky reefs. Although these data support the hypothesis that DMF may decrease abundance of juvenile *C. julis*, it is at present logically impossible to understand which are the specific mechanisms involved in determining the patterns observed, and appropriate experimentation would be needed to discern among possible alternative hypotheses. Differences in juvenile density, for instance, could be attributed to active selection by settling larvae between vegetated and desertified rocky reefs, or to differential post-settlement mortality rates between the two habitats e.g., due to differences in the availability of food and/or shelters against predators (Jenkins and Wheatley, 1998; Guidetti, 2000). From this perspective, serranid fishes (e.g., *Serranus cabrilla* and *S. scriba*) have been observed to prey upon juvenile *C. julis* (pers. obs.). Taking into account that desertification by DMF may affect stretches of rocky coast extending for kilometres, and that post-larvae and juveniles have limited movements, it is fairly unlikely that they could select between desertified and vegetated locations at a distance of several kilometres. The few juvenile *C. julis* detected at the impacted locations, in addition, were in most cases associated with the sparse patches of vegetated substrate, which accounts for the significant variability among replicates (i.e., small-scale patchiness) exclusively detected at the impacted locations. This supports the hypothesis that settling juvenile stages do not select among locations or habitats at large distance (i.e., kilometres) from each other, but they probably redistribute into the few available vegetated patches within the desertified rocky reefs where they initially settle, similarly to what observed in seagrass systems elsewhere (Bell and Westoby, 1986). From this perspective, an issue deserving attention in future studies could be represented by the relationship between the degree of macroalgal-habitat fragmentation caused by DMF, and the success of fish settlement/recruitment.

These results also showed that whole density of adult *C. julis* did not change between impacted reefs and controls. Adult fish are able to swim along rocky reefs for far greater distances than juveniles. Therefore, the presence of adult *C. julis* in desertified areas could be due to migration from other (vegetated) areas where juveniles previously settled successfully, recruited to the adult stock and then spilled over towards adjacent (in some case bare) areas. Obviously, such a mechanism is plausible till there are sufficient areas where settlement/recruitment may occur. Considering, for instance, that desertification by DMF is proceeding pretty fast in SE Italy (Fraschetti et al., 2001), there is the possibility that, beyond a given threshold, recruitment would fail, causing the collapse of local populations of *C. julis* and of any other species using vegetated rocky reefs as preferred or alternative habitat for settlement/recruitment (Garcìa-Rubies and Macpherson, 1995; Harmelin-Vivien et al., 1995; Guidetti and Bussotti, 1997). This could also have important implications for small-scale fishery, an issue deserving specific attention and long-term data to be appropriately assessed.

The data presented here, although far from being conclusive, confirm that the destructive DMF may have consequences well beyond those directly caused by date-mussel fishermen to rocky substrates. It is obviously needed to collect data on more than one species, and in more than a single year to confirm these results, but they anyway contribute to the growing concern about the potential of DMF in altering ecosystem functioning of shallow rocky reefs. To our knowledge no other sorts of human harvesting exists that are able to produce comparable detrimental effects on shallow rocky substrates (see Dayton et al., 1995). Date-mussel poachers usually move from completely devastated to new unexploited areas, which means that desertification of rocky substrates is expanding along the rocky Apulian coast in spite of its formal prohibition. Therefore, these data and the previously published reports (which showed the wide array of detrimental effects of DMF; Fanelli et al., 1994; Fraschetti et al., 2001; Guidetti et al., 2002, 2003, 2004) emphasise once again the need for a more effective patrol against this devastating fishery.

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