J. Mar. Biol. Ass. U.K. (2003), **83**, 27–29
Printed in the United Kingdom

Early patterns of *Caulerpa racemosa* recovery in the Mediterranean Sea: the influence of algal turfs

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Variability in recovery of the introduced green alga *Caulerpa racemosa* has been investigated on a subtidal rocky shore in the north-western Mediterranean Sea. Two removal experiments were performed. The first was designed to test the effects of season on the early patterns of recovery of *C. racemosa* on a rocky bottom and on algal turf. In the second experiment recovery of *C. racemosa* on the rocky bottom and on algal turf was estimated from July–October 2000, the end of the vegetative period of the alga. Recovery of experimental plots occurred from adjacent populations of *C. racemosa* by stolon growth. In the first experiment, recovery occurred from August to November in all the experimental units, while no growth was observed during winter and spring. Recovery was significantly higher on algal turf than on rock during all vegetative periods. In both the habitats, recovery was quicker in summer than in autumn, even if differences between dates within each season were also significant. In the second experiment, three months after removal, the mean per cent cover of *C. racemosa* in algal turf was twice that on rock.

INTRODUCTION

In the Mediterranean Sea, the recent spread of introduced green tropical algae of genus *Caulerpa* represents an environmental emergency (Meinesz et al., 2001). *Caulerpa racemosa* (Forsskål) J. Agardh, in particular, has been invading the eastern Mediterranean since the early part of the 19th Century and, for that, it is considered a lessepsian migrator. In the 1990s, this species has also been colonizing the western part of the Basin (Modena et al., 2000) where it has been indicated as a further new introduction (Verlaque et al., 2000). In the Mediterranean, *C. racemosa* showed invasive characteristics, quickly colonizing wide areas between 0 and 50 m of depth and interfering with native subtidal communities (Piazzi et al., 2001a; Ceccherelli & Campo, 2002). Because of its vegetative reproduction by fragmentation and stolonization (Ceccherelli & Piazzi, 2001), *C. racemosa* is able to grow on every kind of substrate and on other benthic organisms (Piazzi et al., 1997, 2001a). Both these features characterize all *Caulerpa* species and are considered strategies that confer high invasive ability. Also the fast spreading algae *Caulerpa taxifolia* (Vahl) C. Agardh and *Caulerpa scalpelliformis* (R. Brown ex Turner) C. Agardh exhibit the same characteristics.

Although concerns have been aroused by the *C. racemosa* invasion, factors influencing its colonization capability have not been experimentally investigated. Its ability to settle and grow may change in relation both to habitat characteristics and to the presence of other organisms that may either prevent or favour the spread of the alga. Previous studies show different growth rates in habitats constituted by algal turfs or sea grass beds. In this study, two removal experiments were performed to evaluate the influence of season and algal turfs on *C. racemosa* colonization.

MATERIALS AND METHODS

The study was carried out south of Leghorn (43°28′24″N 10°19′42″E) on a rocky platform at 10 m of depth. The bottom was colonized by a macroalgal assemblage dominated by turfs mostly composed of *Womersleyella setacea* (Hollenberg) R.E. Norris and *Acrothamnion preissii* (Sonder) Wollaston. At the site *Caulerpa racemosa* has been spreading since 1996 (Piazzi et al., 2001b) and, at present, it mainly occurs on algal turfs over hard substrata.

In this study two different experiments were performed. The first one was carried out between March 2000 and February 2001 to detect the influence of habitat and time on *C. racemosa* recovery. Removal treatments were performed on two dates randomly chosen within each season, for a total of eight sampling times. Sixteen areas of about 30 m^2 were chosen within the study site and randomly assigned to sampling dates (two areas for each date). In each area, six experimental units 400 cm^2 in size were chosen within *C. racemosa* patches and assigned to each of the following treatments: (i) rocky substrate; and (ii) algal turfs. These treatments were obtained respectively by removal of *C. racemosa* + turfs (total removal) and by removal of *C. racemosa* (partial removal) by gently uprooting it. Three replicates of each treatment were established in each area. To estimate recovery of *C. racemosa*, photographic samples were taken by SCUBA divers 20 days after each removal date. The abundance of *C. racemosa* was evaluated by projection of slides into a matrix of 100 equally spaced dots: per cent cover was assessed by counting the number of dots lying over stolons. Data were analysed by a 4-way analysis of variance (ANOVA), with Habitat (rocks vs turfs) and Season (4 levels) as fixed and orthogonal factors, Date (2 levels) as random and nested in Season, Area (2 levels) random and nested in Date. Cochran's test was performed to check for homogeneity of variances.

The second experiment was carried out from July until October 2000 to investigate *C. racemosa* recovery on a longer period. In each of two areas, six experimental units 400 cm^2 in size were chosen and randomly assigned to each habitat treatment (total removal vs partial removal, as before). Three replicates were attributed to each treatment combination. Per cent cover of *C. racemosa* was sampled in August, September and October, respectively 30, 61 and 91 days after removal, using the previously described method. Data obtained on the last sampling date were analysed by 2-way ANOVA with Habitat (rock vs turfs) as fixed factor and Area (2 levels) as random factor.

RESULTS

Recovery of experimental plots by *Caulerpa racemosa* occurred from the edges of experimental units by vegetative stolon growth of adjacent populations. In the first experiment, recovery showed high seasonal variations (Figure 1) since a partial recovery of the alga occurred in all the experimental units during summer and autumn (from August to November), while no growth at all was observed during winter and spring. However, to avoid heteroscedasticity, winter and spring data corresponding to zero per cent cover (Figure 1) have not been included in the analysis and ANOVA did not detect a significant interaction between Habitat×Season nor the effect of the Season as a main factor.

Also, the analysis showed that *Caulerpa racemosa* recovery was different depending on habitat treatment ($F_{1,32}$=115.75; P=0.0085). In fact, when it occurred (during summer and autumn) it was higher in partial removal treatment than in total removal treatment (Figure 1). Twenty days after removal, per cent cover of *C. racemosa* ranged in algal turf habitat (partial removal) between 35.0 ±3.1% (hereafter mean ±SE, N=6) in August and 15.7 ±1.9% in October. On rock habitat (total removal), values ranged from 13.8 ±1.9% in August to 2.5 ±1.0% in October. Significant differences between dates within the same season were also significant corresponding to the temporal graded rank in algal performance evidenced by Figure 1. Differences between areas were not significant.

In the second experiment, recovery of *Caulerpa racemosa* appeared homogeneous in time from July, when removal was performed, until October (Figure 2). However, significant differences between habitats were observed ($F_{1,8}$= 6346.78; P=0.0080): in fact, three months after removal (in October 2000) per cent cover of *C. racemosa* was 77.8 ±2.3% on algal turf and 38.0 ±2.2% on rock habitat, suggesting a velocity of spread in the former habitat twice as much the latter one. Also, ANOVA showed that differences in cover between experimental areas were not significant.

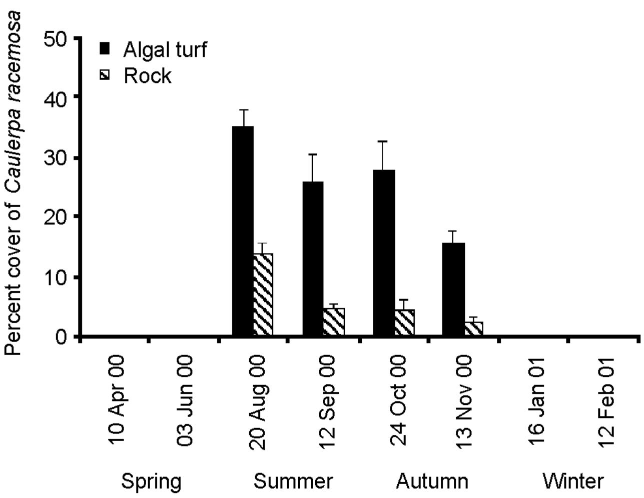

Figure 1. Experiment 1. Seasonal fluctuation of *Caulerpa racemosa* per cent cover on algal turf and on rock 20 days after removal (mean ±SE, N=6). Dates refer to recovery measurement.

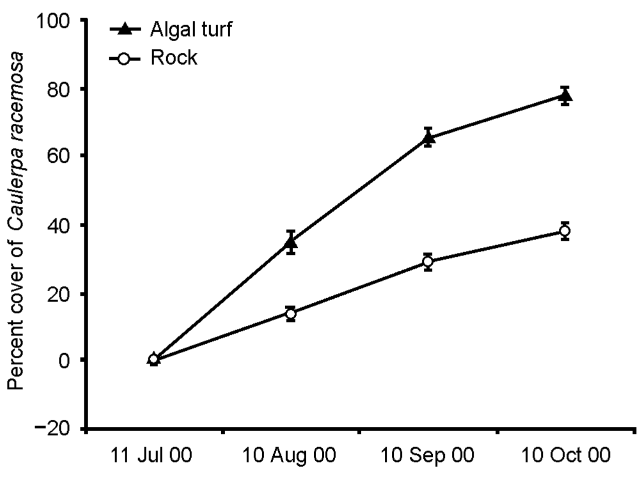

Figure 2. Experiment 2. Per cent cover of *Caulerpa racemosa* on algal turf and on rock 30, 61and 91 days after removal (mean ±SE, N=6).

DISCUSSION

Results of the present work stressed the importance of the role of vegetative propagation for *Caulerpa racemosa* spread, as already highlighted by other experimental studies (Ceccherelli & Piazzi, 2001). Species belonging to *Caulerpa* genus are pseudoperennial algae that may spread through both stolon elongation and fragmentation of thallus and consequent establishment of drifting fragments (Ceccherelli & Cinelli, 1999; Smith & Walters, 1999). These mechanisms are considered more important to the spread of the algae than sexual reproduction and they are believed to confer great invasive ability to *Caulerpa* species introduced in the Mediterranean, such as *C. taxifolia*. The second experiment has confirmed the high invasive potentiality of *C. racemosa*: in fact, in July stolons of adjacent populations of *C. racemosa* began to colonize experimental plots just after removal, and recovery was nearly completed after three months on algal turf.

However, patterns of recovery appeared deeply affected by the time of the beginning of the experiment, reflecting differences in *Caulerpa racemosa* growth rate through the year. Previous studies showed seasonal variations in Mediterranean populations of *C. racemosa* in stolon elongation, blade size (Ceccherelli et al., 2000) and biomass (Piazzi et al., 2001a), as well as for other *Caulerpa* species (Meinesz et al., 1995). Although no growth occurred in winter and spring, the highest recovery occurred in the beginning of summer, showing a capability of *C. racemosa* populations to spread suddenly at the beginning of the warm season. This feature justifies the spectacular increases in algal biomass that regularly occur at sites colonized by the alga.

These data suggest that temporal variations in disturbance may play an important role in the control of *Caulerpa racemosa* spread. Storms, for example, can remove the alga by uprooting fragments from substrate creating patches of clearings similar to the removal of experimental ones used in this study. Results obtained suggest that the recovery dynamics of these patches change greatly depending on the period of the year and that, probably, clearings produced during winter and spring are not recovered until the following early summer period. In fact, the capability of *C. racemosa* to fast secure open space by lateral propagation of stolons allow the alga to recover quickly and persist despite disturbance during the whole warm season.

Algal turf positively affected *Caulerpa racemosa* spread. Although *Caulerpa* species are known to be able to anchor and grow on many kinds of substrate, previous studies have already indicated that algal turf might favour the establishment of *C. racemosa* fragments (Ceccherelli & Piazzi, 2001). In the present work, stolon cover increased significantly where turfs were present in respect to where they were removed. Pre-emption of substrate by turf population generally interferes with macroalgal colonization, especially if algae reproduce sexually (Benedetti-Cecchi, 2000). In rhizophytic species such as *Caulerpa*, the cohesive surface constituted by turfs may affect stolon growth mechanically, favouring both rhizoid attachment and bridling stolons. However, turf normally traps sediments (Airoldi, 1998) leading to physical habitat modifications that may represent a more suitable condition for *C. racemosa* performance. However, further experimental investigations are needed to distinguish the effect of sedimentation from the effect of algal turf structure on *C. racemosa* spread.

At the study site, as well as in many areas of the western Mediterranean, algal turfs are mostly composed of the introduced red algae *Womersleyella setacea* and *Acrothamnion preissii*. The occurrence and the abundance of algal turfs have been increasing during the last decades (Piazzi & Cinelli, 2000), probably because their presence is favoured by high sedimentation rates that are linked to the human activities. Results of this study indicate that synergistic effects between introduced macroalgal species in the Mediterranean have to be considered. Although occurring also on bare rock, *Caulerpa racemosa* colonization appeared positively affected by the presence of algal turfs. Both the mechanisms and the outcome of interactions between invasive Caulerpae and turfs need further investigations so that predictions on a longer term could be made and synergisms between man-induced changes could be stressed.

This work was supported by SINAPSI research project (MURST–CNR programme). We wish to thank J. Bothwell for his helpful comments that improved the quality of the manuscript.

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Submitted 3 April 2001. Accepted 9 December 2002.