How an invasive alga species (*Caulerpa taxifolia*) induces changes in foraging strategies of the benthivorous fish *Mullus surmuletus* in coastal Mediterranean ecosystems

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Received 19 May 2003; accepted in revised form 20 October 2003

Key words: Benthivorous fish, *Caulerpa taxifolia*, Conservation, Foraging behaviour, Invasive algae, Mediterranean ecosystem, *Mullus surmuletus*

Abstract. The foraging behaviour variability of three striped red mullet (*Mullus surmuletus* L. 1758) populations with respect to the vegetation cover was examined along the French Mediterranean coasts. We tested both the carrying capacity of different habitats and the hypothesis of a food segregation by the invasive alga *Caulerpa taxifolia* (Vahl) C. Agardh, on the functioning of benthic fish populations. The results indicated a significant site effect on *M. surmuletus* foraging behaviour and movements. The vegetation cover may play an important role in modifying the striped red mullet cost of foraging (sampling effort) and thus its strategy of prey capture. As long as the cover of marine phanerogams and/or macrophyte algae (*Caulerpaceae*) increases, the foraging budget and the distances covered in search of prey decrease significantly. Similarly, the striped red mullet increases the prospected sample periods to augment its foraging success, swimming above the bottom. These changes are related to the development of a dense superficial network of plagiotropic rhizomes and stolons, and to the reduction of space between fronds that limits the accessibility to resources and may increase intra-specific food competition. The role of *C. taxifolia* does not differ from that of other marine phanerogams but induces significant changes in the structure of Mullidae populations at the local level. The rapid expansion of *Caulerpaceae* in the Mediterranean Sea could constitute a real threat for the balance of the marine coastal biodiversity and the ecology of *M. surmuletus*, which is considered a flagship species for coastal Mediterranean demersal fisheries.

Introduction

For 20 years, the increased urbanisation of the Mediterranean coastline, as well as coastal tourism and fishery activities have threatened the long-term survival of various marine ecosystems (Francour et al. 1999; Harmelin-Vivien 2000). In order to avoid a drastic reduction of the biodiversity and a negative feedback effect on the local economy along the French, Spanish and Italian coastlines, the monitoring of marine ecosystems and the improvement of fishing techniques has become a priority in terms of management (Pinnegar et al. 2000; Francour et al. 2001; Kaiser et al. 2002). Approximately 10 macrophytic allochtonous algal species currently have been identified as a threat to the coastal and infra-coastal ecosystem balance in the Mediterranean (Verlaque and Fritayre 1994; Boudouresque and Verlaque 2002).
The most emblematic species due to its high growth rate and rapid spreading is *Caulerpa taxifolia* (Vahl) C. Agardh. Discovered in 1984 in Monaco (N43°33’53.0”; E7°25’36.1”; Meinesz and Hesse 1991), its actual distribution area now includes Spain, Croatia, Tunisia, and even California (Gili 2000; Jousson et al. 2000; Langar et al. 2000). Temperature, light intensity, depth and habitat types have permitted its large seasonal variations of covering and biomass. The biomass reaches an average between 5100 and 13,920 fronds·m⁻² (max: 25,000 fronds·m⁻²) without any decrease of covering in colonised areas (Meinesz et al. 1995; Komatsu et al. 1997; Ceccherelli and Cinelli 1998). Thus, added to fishery constraints, the colonisation by *C. taxifolia* induces significant changes in ecosystems with serious threats at the habitat and plant diversity levels as well as for echinoderms and benthivorous fish assemblages (Boudouresque et al. 1995, 1996; Francour et al. 1995; Harmelin-Vivien et al. 1999).

Thus, we studied populations of benthivorous fish whose densities have been affected by the introduction of *C. taxifolia*. The striped red mullet species (*Mullus surmuletus* L. 1758) was studied. The biology and the trophic ecology of this species is currently well known (Golani and Galil 1991; N’Da and Deniel 1993; Labropoulou et al. 1997). Nevertheless, despite its economical value, any fish farming concession can allow the rapid embryogenic development and growth of juveniles for this species (Suquet and Person-Le Ruyet 2001) submitted to high fishing pressure in the Mediterranean (catches increased by about 70% in 20 years; Reñones et al. 1995; Coppola 2001). Thus, the stability of Mullidae populations already appears critical on the Italian and Spanish coastlines (Suquet and Person-Le Ruyet 2001).

We tested the local adaptability of the striped red mullet foraging and prey capture strategies with respect to the type of the vegetation cover and structure. Based on the hypothesis of a food segregation by *C. taxifolia*, we also investigated the differences in fish population structure among and within sites.

**Material and methods**

The analysis of foraging strategy and movement of *M. surmuletus* with respect to the vegetation composition and covering were performed in three geographically distinct areas located on the eastern French Mediterranean coasts (Alpes Maritimes, Figure 1). Two sites are colonized by *Caulerpa prolifera* (Forsskål) Lamouroux and/or *C. taxifolia* (Golfe Juan bay, N43°34’, E7°05’; Menton, Cap Martin, N43°45’, E7°29’) whereas the third is characteristic of *Posidonia oceanica* seagrass beds (Cap d’Antibes, La Garoupe beach, N43°33’, E7°08’). At each site, all the observations were made in the fall (September, October) by the same underwater skin diver from 9:30 to 17:00, according to visual censuses on linear transects along the coastline from 0 to −10 m depth. A total of 33 groups of striped red mullet (92 individuals) were followed continuously for 12 min minimum. For each group, the number of individuals per size class (small < 10 cm < medium < 20 cm < large) were noted. Behaviour was recorded according to three modalities (foraging, swimming, inactivity). The duration of each modality was evaluated using a waterproof chronometer and the