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Inshore capture-based tuna aquaculture impact on *Posidonia oceanica* meadows in the eastern part of the Adriatic Sea

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ABSTRACT

Mapping and monitoring of the seagrass *Posidonia oceanica* in the eastern (Croatian) part of the Adriatic Sea since 2004 indicates a significant decline in meadow density in an area impacted by inshore capture-based tuna aquaculture. The density and overall condition of *P. oceanica* meadows impacted by tuna farms near Fulija Islet was compared to two reference sites (Iž Island and Mrtovnjak Islet). The factors with the most significant influence on *P. oceanica* meadows were found to be the input of organic matter originating from the cages, as well as high epiphyte biomass caused by nutrient enrichment. Significant differences in nutrient concentrations were found between the sites impacted by tuna farms (Fulija Islet) and the control stations. Shoot density of the *P. oceanica* meadows decreased at the stations in close vicinity to the tuna farm, which suggests that the tuna farm activity strongly affected the surrounding meadows.

1. Introduction

Posidonia oceanica meadows play a crucial role in the systems of the Mediterranean and Adriatic Sea, both biologically and economically. Seagrasses represent an important food source for benthic consumers, offer refuge from predation to several benthic species, act as a nursery area for commercial fish juveniles, enhancing habitat complexity, modifying sediment texture and hydrodynamic regime (Duarte, 2002; Holmer et al., 2008). In addition, *P. oceanica* meadows produce large quantities of organic matter, which constitutes the basis of aquatic food webs and represents the main food source, both in this and other ecosystems (Pergent et al., 1994).

Significant deterioration of *P. oceanica* meadows has been observed in several sectors of the Mediterranean coastal zone, in particular around conurbations and large industrial port centres (Boudouresque, 2003). The severe impact of human activities has negatively affected the evolution and survival of this sensitive taxon, despite legal measures being undertaken in many Mediterranean countries (Ruiz and Romero, 2003). Areas covered by these meadows have been significantly reduced in the Mediterranean Sea in the last 50 year (Ardizzone et al., 2006; Pergent-Martini et al., 2006). Through signing international conventions (e.g. Barcelona, 1976/1995, Bern, 1979, Rio, 1992), coastal countries took an obligation to conserve and protect marine vegetation, especially marine spermatophytes, such as the endangered *P. oceanica,* an endemic species of the Mediterranean Sea. Although there are signs of the degradation of *P. oceanica* in the Croatian part of the Adriatic, competent authorities have not yet undertaken appropriate measures for its protection.

In the last 40 years, the seagrass *P. oceanica* has suffered a significant decline in most Mediterranean areas, which can be attributed to a wide array of causes, most of which are related to anthropogenic activities, such as industrial and urban sewage discharges (Pérès, 1984; Bourcie, 1989; Pergent-Martini and Pergent, 1995; Pergent-Martini et al., 2006), fish farming (Delgado et al., 1997; Ruiz et al., 2001; Holmer et al., 2008; Papageorgiou et al., 2010), trawl fishing (Ruiz et al., 1999) and coastal works (Astier, 1984; Blanc and Jeudy de Grissac, 1989; Ruiz et al., 1993; Guidetti and Fabiano, 2000). The recent increase in fish farming in the Adriatic Sea has imposed additional pressure on *P. oceanica* meadows.

As cages are frequently installed in sheltered areas, such as bays or coves, in relatively shallow waters, they impose significant pressure on the littoral fringe, making seagrass meadows one of the most susceptible habitats. According to Katavić et al. (2002), most of the tuna farms in Croatia are located in very shallow areas with poor water exchange. There is also a lack of environmental monitoring on the effects of tuna farms on the quality of water

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and sediments. Fish farms often compete spatially with other human activities and are, in some cases, in conflict with attempts to protect valuable natural areas. Lack of historical references for the Adriatic Sea, along with high costs of new surveys in the area, prevent any continual widespread monitoring programme.

Fish farming produces high organic matter and nutrient loading into the surrounding water, affecting the ecosystem by causing significant deterioration of water quality, and is likely to be responsible for changes such as the degradation of seagrass meadows (Holmer et al., 2003; Pergent-Martini et al., 2006). *P. oceanica* usually grows in well oxygenated sediments with low amounts of organic matter. Recent studies have shown that organic matter enrichment of seagrass meadows from fish farm facilities results in high plant mortality (Delgado et al., 1999; Pergent et al., 1999; Ruiz et al., 2001), indicating that *P. oceanica* is sensitive to organic enrichment and reducing conditions within the sediment. Meadows of *P. oceanica* disappear below fish cages, while surrounding areas are significantly degraded. Excess fodder, together with fish faeces, are released into the environment and account for the high input of organic matter which sinks to the bottom, disturbing the benthic flora and fauna and causing profound changes in sediment chemistry (Wu, 1995; Karakassis et al., 1999; La Rosa et al., 2002; Belias et al., 2003; Cancemi et al., 2003; Holmer et al., 2003). Physico-chemical changes in the water and sediment result in a reduction of seagrass abundance beneath fish cages and in surrounding areas. Other factors can also negatively affect these populations, for example an epiphytic bloom that shades the seagrass leaves, or an increase in grazing pressure by fish and sea urchins. All aforementioned factors affect the carbon balance of the plant and negatively affect seagrass health and survival. This indicates that the sensitivity of *P. oceanica* is related to human activities, and justifies its use as a biological indicator of water quality of coastal Mediterranean areas. However, some field studies on water column characteristics in the vicinity of fish farms have shown little or no effect of dissolved wastes, and concluded that any effect on water quality is likely to occur on smaller spatial scales (Nordvarg and Johansson, 2002; Karakassis et al., 2005).

Relatively few studies have addressed the issue of dissolved nutrients in Mediterranean fish farms and no general pattern has emerged. The organic waste products from the intensive cultures are released in dissolved form (80–90% of the total organic carbon) or as particulates (10–20%) directly in the seawater column in a highly biologically active form. A large fraction of organic substances in seawater possesses surface-active properties and accumulates at the seawater-atmosphere boundary, as well as at boundaries with dispersed and particulate material, and with sediment (Hunter and Liss, 1981; Ćosović et al., 1985; Marty et al., 1989).

When considering the implementation of fish farm cages in the vicinity of *P. oceanica* meadows, a minimum distance of 200 m should be respected. This generally corresponds to the effective area of impact on the benthos (Doglioli et al., 2004). This distance should be increased near the meadow's lower limit (higher sensitivity to turbidity than shallow-water meadows) and varied in function to currents and the size of the fish farm (Pergent-Martini et al., 2006).

In this study, we investigated the remote influence of waste originated from an offshore fish farm complex on a *P. oceanica* meadow, and its impact on the condition of the seagrass. We observed *P. oceanica* meadows near fish farming cages around Fulija Islet, Eastern Adriatic Sea, Croatia, to assess the responses of this seagrass to organic matter enrichment in marine sediments. We analysed both meadow features and plant performances along a transect from disturbed towards undisturbed areas (control sites). In addition, to determine the impact of fish farming on seawater quality, we measured nutrient concentrations and oxygen saturation at various depths in the water column, as well as organic matter within the sediments.

The objective of this study was to establish a general relationship between nutrient input rates and loading of organic matter from the tuna farm near Fulija Islet, and *P. oceanica* population dynamics. We hypothesize that fish farms have a negative effect on *P. oceanica,* and we therefore expect to observe an increase in shoot mortality and changes in meadow structure, depending on distance from the farm.

Numerous changes were observed in the *P. oceanica* meadows near Fulija Islet. The density (number of shoots per m^2) showed a significant decrease in the vicinity of the cages, to a distance of up to several hundred metres from the cages during our surveys in 2004. The mean density of *P. oceanica* measured at the fish farm facilities was usually lower compared with density values regarded as 'normal' for certain depths (according to Pergent et al., 1999). We also re-examined the condition of the *P. oceanica* meadows near Fulija Islet in 2011 and 2013 (3 and 5 years after tuna farming cessation, respectively) with a view of possible regression, in terms of size or vitality.

2. Materials and methods

2.1. Study area

The studies were carried out in the area of Fulija Islet (44°01′02″N, 15°06′42″E), which was under the influence of a tuna farm facility (Fig. 1). The small islet of Fulija, located south-west of the island of Iž, was the first farm to begin with this type of fish production in the Mediterranean Sea. The tuna farm near Fulija Islet, together with the tuna farm near Kudica Islet (3 km north from the Fulija Islet) produce more than 1500 tons of tuna-fish per year. Our control sites were selected based on their similarity in seafloor morphology and depth to that of the corresponding tuna farm.

Shoot density was measured along four linear transects near the tuna cages (P1–P4) and at two control stations (K1 – Iž Island) and (K2 – Mrtovnjak Islet), located approximately 4 km away from the tuna cages (Fig. 1). The four linear transects covered a depth from 5 to 25 m, as well as various distances from the fish farm (P1 – 50 m from the cages; P2 – 100 m from the cages; P3 – 300 m from the cages and P4 – 600 m from the cages). Continuous meadows of *P. oceanica* are present at the study sites along the western part of Fulija Islet, and at the control stations from 3 to 30 m depth, mainly colonizing muddy coarse sand. In the vicinity of the tuna farm (station P1), we observed a weak meadow with extensive areas of dead matte at a depth of 10 m.

Ecological variables were measured in March, June, October and December 2004 and May 2005 at stations F1, F2, F3, and F4, as well as at three control stations K1, K2 and F5. Station F1 (Fulija Islet) is located 50 m from the tuna farm, while the distances of other stations from the cages were 100 m (F2), 300 m (F3), 1000 m (F4) and 3000 m (F5).

2.2. Sampling and analysis

Sampling of *Posidonia oceanica* was conducted by means of SCUBA diving. The density of the seagrass bed (number of shoots per square meter) was estimated at each site using a 50 × 50 cm quadrate, with 10 replicates per station. For estimation of epiphyte load, samples of *Posidonia* leaves were collected during the summer period. Epiphytic algae were scraped from the entire leaves (5 leaves per shoot, minimum 10 replicates), dried for 48 h at 75 °C, after which the total dry weight per shoot was determined.

Sediment samples were taken in October 2004, 2011 and 2013 at a depth of 10 m at all sites, with PVC sediment corers (5 cm in